SPECTROGRAPHIC STUDIES OF THE AURORA POLARIS AND THE AIRGLOW

by

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C O N T E N T S

(3)/

Spectrographic Studies of the Aurora Polaris and the Airglow.

I. INTRODUCTION.

Fifty years ago very little was known about conditions in the earth's atmosphere above a height of a few kms. and such ideas as did exist were mainly speculative. Since then, however, much work has been done, powerful new techniques developed, and a store of information accumulated about the inaccessible region above the maximum height of balloon ascent where no direct measurement has been possible until the recent development of high altitude rockets. Indirect methods have been used and one of the most successful of these has been the spectrographic study of the light emitted by these regions. The most intense source of this is the "northern lights" or aurora polaris. Although this phenomenon has been observed and classified for many years - Seneca[1], in the first century A.D. gives a description of it.- it was not until Vegard[2] and his collaborators in the second decade of the present century analysed its light spectrographically that it was used to provide qualitative information about the condition of the upper atmosphere. The aurora occurs irregularly and is most frequent in a region known as the Auroral zone centred $23\frac{1}{2}^{\circ}$ from the poles. In addition to this transient phenomenon Rayleigh found that there was emitted from the earth's atmosphere/

lines of the spectrum. This was not a very satisfactory state of affairs as it would have been of great interest to have examined and compared spectra obtained from different phases of a display. However, it was found that if the size of these prism instruments was increased, very little gain in sensitivity was achieved as the absorption of the large prisms involved and the reflections from the many optical surfaces required effectively reduced the theoretical gain to negligible proportions. Thus the desire to have simultaneously high resolution and high light power was found impossible with prism instruments using traditional optics. Vegard[4] overcame this in his later work by using low dispersion instruments of maximum power to investigate the variations in intensity of the more prominent lines of the spectrum and larger dispersion instruments over long periods to obtain details of the spectrum.

Those who were investigating the airglow were in an even less fortunate position as the intensity of the source they were dealing with was much less than that of the aurora. When using low dispersion instruments with optics of speeds of nearly f/I, which is at the limit of conventional design, exposure times for useful plates were of the order of 30 to 60 hours. As with the aurora this meant that all spectra obtained were the integrated effects over these long exposure times./

times. This was not very satisfactory but a practical limit seemed to have been reached in the development of the instruments.

With the invention by Schmidt[5] of a camera system which can have speeds considerably faster that f.I. a new tool was available for further progress. Meinel in America designed a special auroral spectrograph using Schmidt's principle. As the dispersive medium he chose a reflecting grating so as to reduce the loss of light and to give nearly uniform dispersion throughout the range. He kept the optical components down to a minimum, used reflecting surfaces wherever possible, and incorporated a Schmidt camera of f/0,7. This type of instrument has tw ice the range of a prism instrument and can be used from ultra-violet to infra-red with a combination of very high light power and a uniform dispersion of convenient size. Also using modern "blazed" gratings a high percentage of the light can be concentrated into a single order so increasing the efficiency still further.

A few instruments have been built to this pattern. One of these - the instrument used in this investigation - has been lent to St. Andrews Observatory by the Cambridge Air Force Research Centre, Massachusetts, U.S.A. for use over the International Geophysical Year period 1957-58.

It was planned that in the first instance the following problems should be examined:

(1) Measurement of the wavelengths of the lines and bands in the auroral and night airglow spectra over as wide a range of wavelengths and intensities as possible.

(2) Estimation of upper atmosphere temperatures from the profiles of suitable nitrogen bands.

(3) Investigation of the enhancement of the sodium D lines at twilight.

II. THE SPECTROGRAPH.

When ready for use the spectrograph at St. Andrews was set up as shown in the accompanying plan and plates I - IV. The main components of the instrument are (1) an external lens (2) slit mechanism (3) 45° quartz prism (4) concave spherical mirror (5) plane diffraction grating (6) Schmidt camera. Before these are described in detail their function in terms of the path of a beam of light through the instrument is considered.

Light from the source under investigation, assumed at infinity, falls on the external lens. This lens is so placed as to bring a parallel beam of light to a focus on the jaws of the slit. After passing through the slit, the beam of light diverges and is totally internally reflected at the back face of the quartz prism. From there, having been deviated through an angle of approximately 90° into the direction of the axis of the/

PLATE I

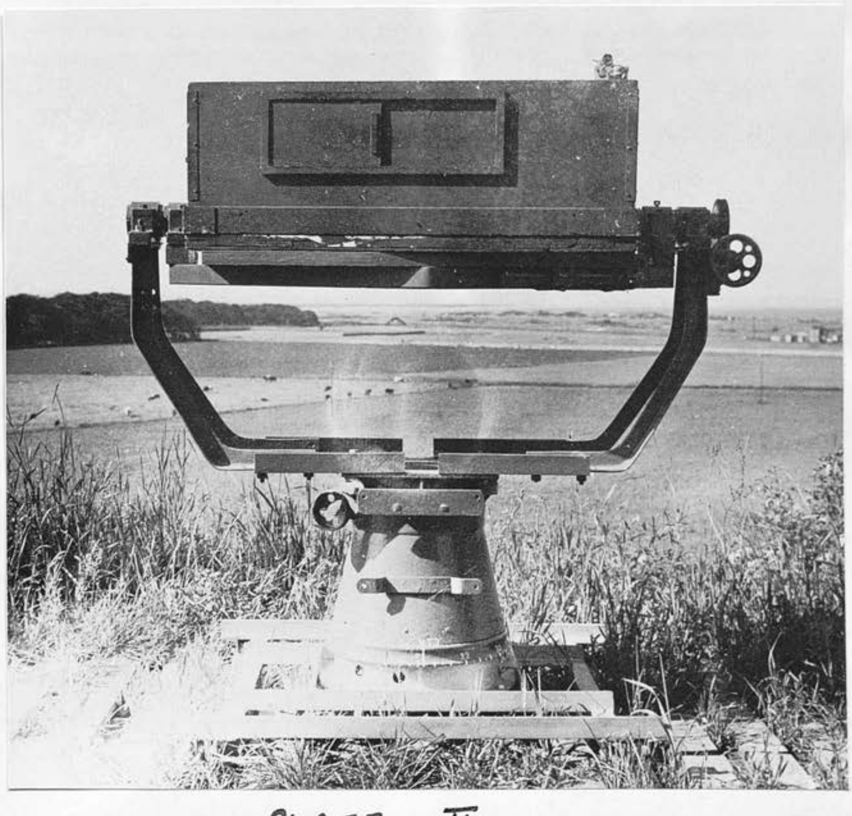


PLATE II

the collimator, it continues to diverge until it strikes the collimator mirror. The aperture of the external lens is so adjusted that it is matched into the mirror. This means that the mirror is completely filled with light and the f numbers of the lens and mirror are equal. The slit is set at the focus of the mirror so that after reflection at the mirror the beam of light is parallel. Some of this parallel beam is blocked out by the prism but as the beam has a cross-section equal to the diameter of the mirror, this is only a small fraction of the total. The beam then falls on to the plane reflecting grating where the light is dispersed, each wavelength being diffracted into a particular angle according to the grating theory given below. These diffracted beams then fall on to the Schmidt plate of the camera, are reflected by the spherical concave mirror in the camera and are focused on to the photographic plate held in the plate-holder at the focal plane of the mirror. The images produced on the plate are the reduced images of the slit in the particular wavelengths of the light falling on the Schmidt plate, i.e. a spectrum is formed, the wavelength region covered being controlled by the angular position of the grating which can be selected at will. These components are so arranged that the centre of the reflecting face of the prism and the centre of the grating are on the axis of the collimator. The axis of the camera also passes through/

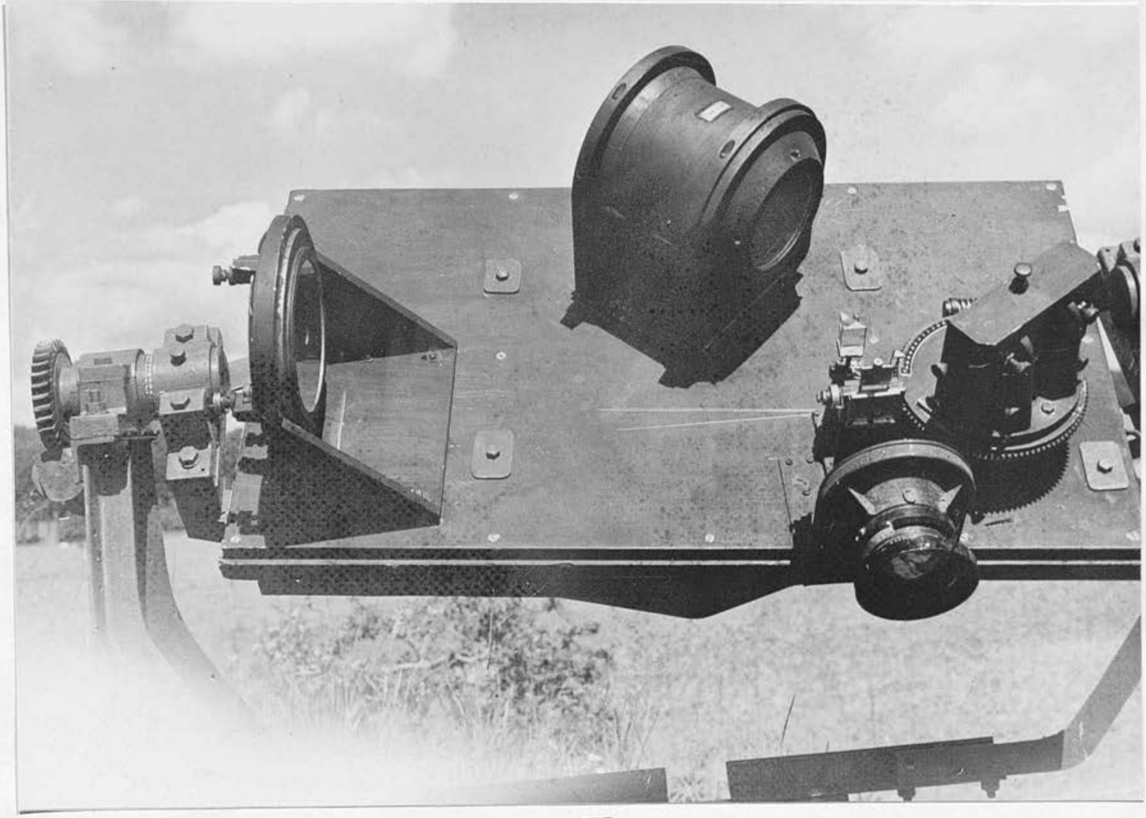


PLATE III

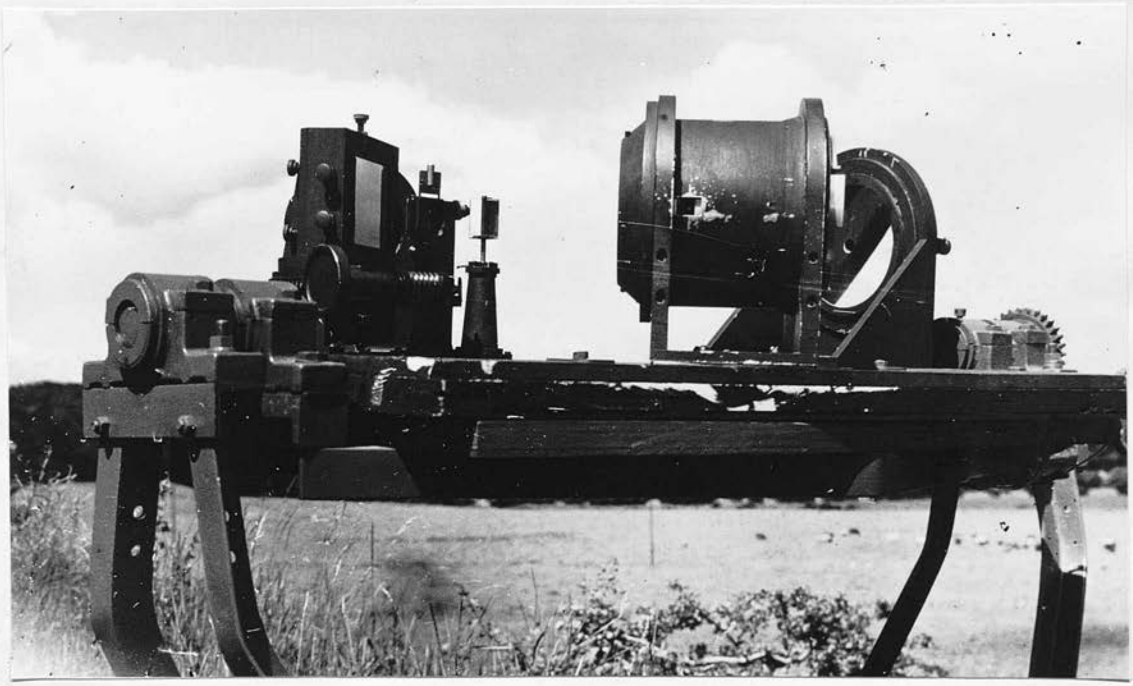


PLATE IV

through the centre of the grating. The plan of the grating and the Schmidt plate are both at right angles to the beam.

(1) THE EXTERNAL LENS

The external lens fitted is a Kodak Aero-Ektar f/2.5, focal length 7 ins. This was included so that, if sources of great brilliance and variable intensity were to be examined, the spectrum of the light from a particular feature of such a source could be obtained by arranging that the image of this feature fell on to the opening of the slit. This would only be possible if the source were bright enough for its image on the slit jaws to be seen. For normal, weak and medium intensity auroral displays and for all airglow work this proved to be impracticable so the lens was removed as it reduced by reflection and absorption the intensity of the light passing into the instrument.

Without the lens in position the light passing into the instrument is limited by the diameter of the collimator mirror and the jaws of the slit. As the mirror has a speed of f/4.24 this is a cone of half angle approximately 7^{o}.

(2) THE SLIT MECHANISM

The slit mechanism (see plate V) is bilateral, the position of both jaws being controllable by a screw which has a scale giving/

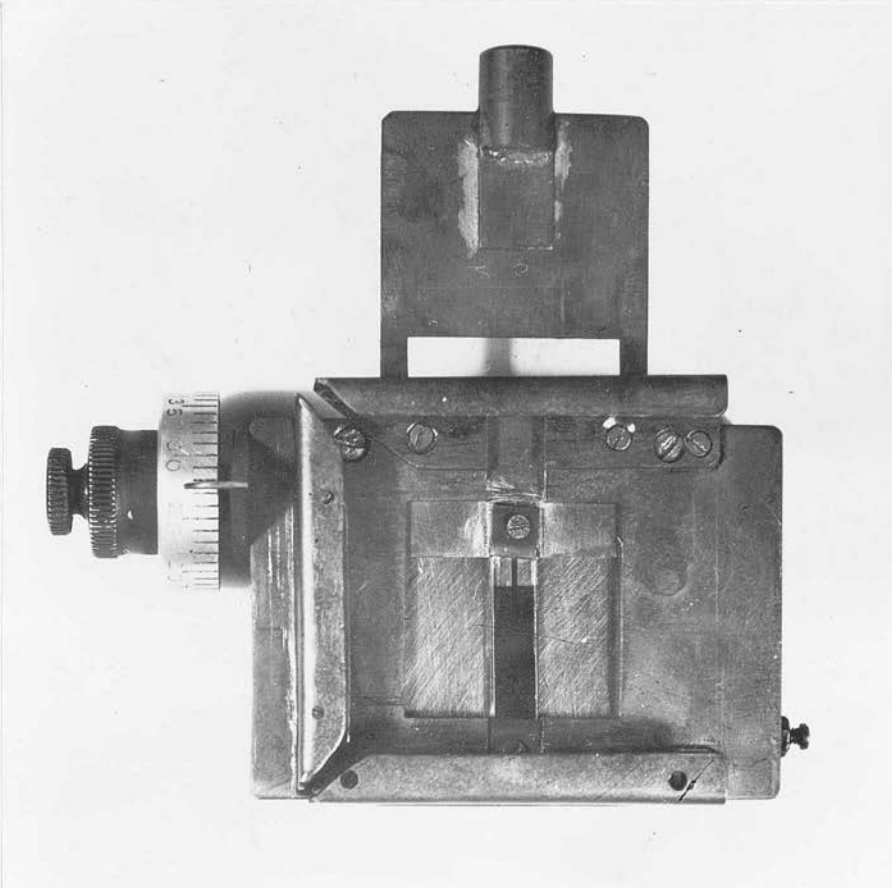


PLATE V

giving a measure of the slit opening. One revolution of the screw opens the jaws ½mm. and the scale is divided into 50 divisions. Thus each division is equivalent to 10μ. (MICRONS) For wavelength measurement of auroral spectra the slit width used was 200μ and for the intensity measurements of the lines enhanced at twilight the slit width was increased to 500μ. The length of the slit opening is 1 inch.

A special shutter was mounted in front of the slit and as close to it as possible. This has two positions. In the first, only the upper ¼" of the slit is exposed. This is used to place the comparison spectrum for wavelength measurements on the plate. The second position exposes the lower ¾" through a step reducer, the upper ¼" being closed. This position can be used to juxtapose the auroral spectrum to the comparison spectrum. The step reducer is included to facilitate intensity measurement (see page 27). In front of the shutter is a filter holder; filters being on occasion necessary to select a particular wavelength region or spectral order. OK see p27

(3) THE PRISM

The 45° quartz prism is mounted on top of a pillar (see plan and plates III and IV) and is capable of limited adjustment. The axis of the light path through the external lens, slit and prism was offset from the line joining the centre of the mirror to/

to the centre of the grating by about 6° from the perpendicular. The reasons for this are given on page 21.

(4) THE COLLIMATOR

The collimator mirror is a concave aluminised spherical mirror with a focal length of 724mm. and a diameter of 171mm. The speed is therefore f/4.24. It can be moved through small angles in both the vertical and horizontal planes by means of four adjusting screws at the rear of the support (see plate III and plan).

If a lens system had been chosen instead of a mirror for the collimator there would have been no need for a prism and all the light from the collimator would have been able to fall on the grating. With a lens, however, there are the inevitable losses from reflection and absorption, and the designer of this instrument considered that the high efficiency of an aluminised surface over a large wavelength range more than compensated for the light obscured by the prism. Moreover the losses are less serious than at first appears, for the plate holder in the camera in any case masks off more than half of the light obscured by the prism.

(5) THE GRATING

The grating is a Bausch and Lomb replica grating 5" x 4" with 600 lines/mm blazed at an angle of 19° 16'. This blaze

occurs/

occurs on one side of the normal at approximately 1,000 A in the 1st order and 5,500 A in the 2nd. The grating is supported in a metal box (as shown in the plan and plates III and IV) with a protecting shutter which can slide over the ruled surface. By means of nine screws its position in vertical and horizontal planes can be set so that it is perpendicular to the incident light beam with the grooves parallel to the slit.

It can be rotated into any desired angle relative to the incident beam by means of the worm and screw shown. The centre of this rotation coincides with the centre of the reflecting face of the grating. A cone bearing is used to ensure maximum rigidity during rotation. Unfortunately the grating when first received was found to be somewhat blemished - it appeared to be spotted with oil and scratched in places. Efforts to improve this were not very successful.

Outline of the theory of the plane diffraction grating.

The fundamental equation for a plane diffraction grating is

$$b(\sin I + \sin I') = m\lambda$$

where b = distance between rulings on the grating.

I= angle of incidence of the light falling on the grating.

and m = order of the spectrum into which particular wavelength is diffracted at angle I' to the normal.

Differentiating this equation with respect to λ gives the angular dispersion $\frac{dI'}{d\lambda}$

i.e./

$$\text{i.e. } \frac{dI'}{d\lambda} = \frac{m}{b \cos I'}$$

From this the linear dispersion $\frac{ds}{d\lambda}$ on the plate may be calculated

$$\text{as } \frac{ds}{d\lambda} = f\frac{dI'}{d\lambda}$$

where s is distance measured along the plate and f the focal length of the camera.

$$\frac{ds}{d\lambda} = f\frac{dI'}{d\lambda} = \frac{fm}{b \cos I'}$$

or in terms of the plate factor $\frac{d\lambda}{ds}$ in A/mm.

$$\frac{d\lambda}{ds} = \frac{b \cos I'}{fm}$$

With this instrument working at the blazed wavelength in the second order the angle of incidence $I = 40^{o}$ and angle of diffraction $I' = 0$

as $f = 100$mm $m = 2$-(second order) and $b = \frac{1}{600}$ m.m.

$$\frac{d\lambda}{ds} = \frac{10^7}{\cancel{1200}\text{x}100} = 83.4\text{A/mm.}$$

The measured value of the dispersion in the second order near 5,500 A i.e. at the blaze angle, is 83 A/mm. which is in good agreement with this calculated value.

As I' is zero at the blaze wavelength cos I' differs only very slightly from 1 for quite a large wavelength region near this point and so the dispersion is effectively linear.

(6) <u>THE SCHMIDT CAMERA</u>

The camera is a classical Schmidt, focal length 100 mms. diameter/

diameter 128mm. hence speed f/0.78. It consists of a Schmidt plate placed at the centre of curvature of a concave spherical mirror. This corrector plate is made of quartz and is contoured so as to correct for the spherical aberration and astigmatism inherent in the mirror. This correction applies to beams not parallel to the axis - an essential property for use with a diffraction grating. The corrector plate is so aligned that the centre of the contoured surface is on the axis of the mirror and in a plane at right angles to it. The focal plane is curved and in order to flatten it over the area of the plate a plano-convex lens is placed in the plate-holder support immediately in front of the plate. The plate holder shown in plate VI has two positions:- (1) for use when not in the instrument, the casing being nearly light-tight, (2) for use when the camera is loaded, the plate being held in the focal plane. To produce sharp lines the plate must be accurately positioned in the focal plane - an error in this position of 0.001 in. makes a noticeable difference in the sharpness of the line. This setting is controlled by a screwed ring at the back of the camera. In order to hold the plate holder rigidly and in the same place at each exposure two magnets are built into the plate holder support. These details can be seen in the plan.

It was not found necessary to include any temperature control/

control system as no variation in focus with temperature could be detected.

The theoretical value of the f number of the camera has been quoted as f/0.78. This is based on the assumption that the whole of the optics is filled with light. In practice this is not so because (a) some of the light is blocked out by the prism and the plate holder support, and (b) the grating is only 4" high while the diameter of the camera is 5" so that there is a ½" strip at the top and bottom of the camera receiving no light. The area from which the light is blocked out from these two causes has been measured and found for (a) to be 4.3 sq.ins. and (b) to be 2.1 sq.ins. Therefore out of a total area of 19.6 sq.ins., 6.4 sq.ins. are blocked out.

Effective area of Schmidt plate	=	13.2 sq.ins.
" diameter	=	4.1 ins.
Hence effective f number	=	0.96

Now the light-gathering power of the camera is proportional to diameter of aperture squared.

Ratio of $\frac{\text{effective}}{\text{theoretical}}$ light-gathering power

$$= \left(\frac{4.1}{5}\right)^2 = 0.67$$

Therefore the light-gathering power is reduced by 33% from the theoretical value by the blocking out of the light by these two causes.

The/

The image of the slit is reduced in the ratio of the focal length of the collimator to the focal length of the camera, i.e. by approximately 7:1. This greatly increases the intrinsic intensity of the image and enables a wider slit to be used than would otherwise have been possible without loss of resolution.

(7) THE MOUNTING

All the components are mounted on a strong wood base-board over the top of which is fitted a light tight wooden box. This box is painted black to prevent light not directed into the camera from being reflected into it from the walls of the box and so producing "ghost" lines. On the side of the box just behind the external lens there is a shutter which when open allows the light to enter the instrument thus enabling the exposure to be controlled. There are three other openings on the box which allow the instrument to be loaded and adjusted without removing the cover (see plate II). A piece of black cloth can be hooked round the external lens support to prevent any stray light from entering the instrument obliquely. A gun sight was placed on top of the box for sighting purposes. (see plate I). The special shutter in front of the slit is operated by a rod from outside the box.

The/

The box was fixed on to a modified ex-naval searchlight mounting to enable the instrument to be pointed at any desired part of the sky. The vertical and horizontal movements of the mounting were calibrated so that sources of particular altitude and azimuth could be selected.

The mounting was secured (see plates I and II) to a wheeled trolley running on rails so enabling the instrument to be pushed out of its hut to command a clear view of the northern sky right up to the zenith and beyond. Inside the hut an optical bench was set up from which a parallel beam of light could be made to fall into the instrument to provide a comparison spectrum, a copper arc being the source.

(8) PHOTOGRAPHIC EQUIPMENT

The design of the instrument necessitates that the plate holder be as compact as possible (see plate VI). This means that the plates themselves are small - in fact $\frac{3}{8} \times 1\frac{3}{16}$". Only a portion of this area is exposed, the maximum area covered by the spectrum being 3.6 x 17mm.

The plates used were Kodak spectrographic plates, types 103a-O and 103a-F. These are specially sensitised for wavelength regions. 2,500 - 5,000A and 4,600 - 6,900A respectively. The size of these plates when received was 10" x 4" so they/

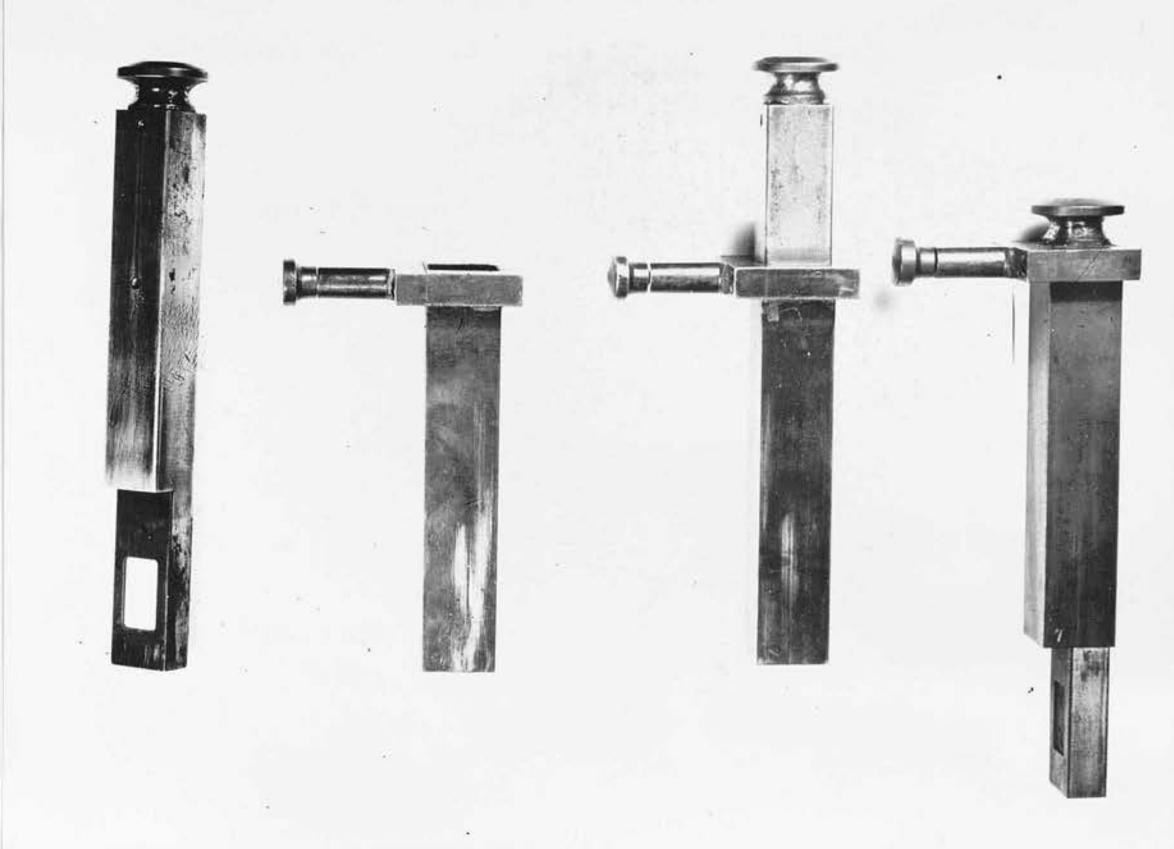


PLATE VI

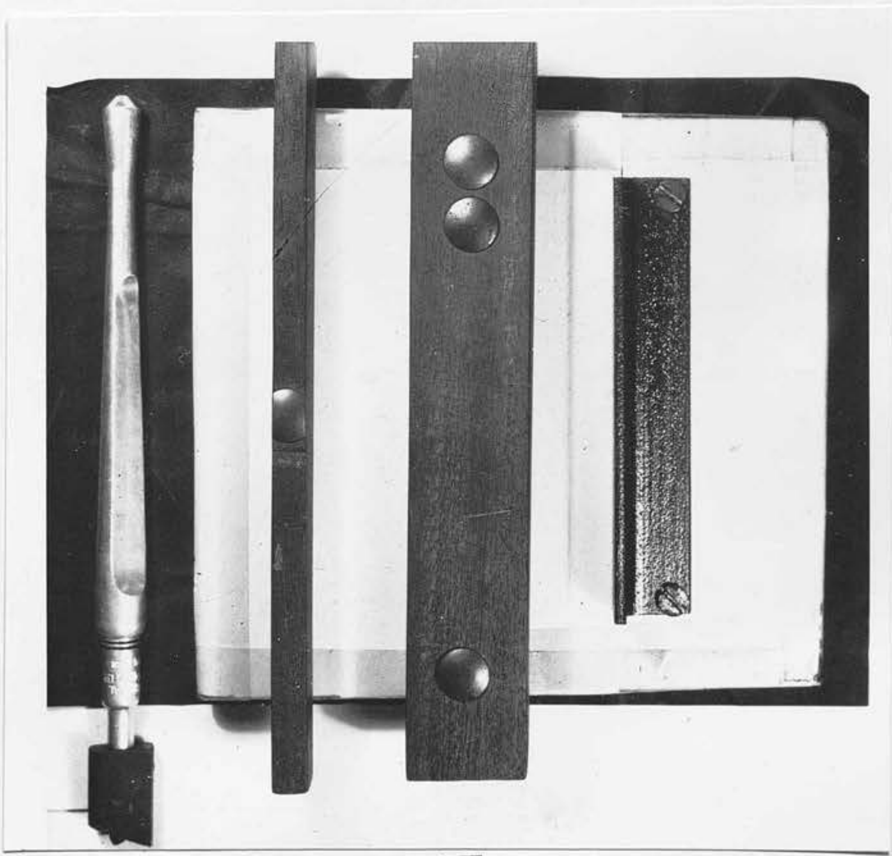


PLATE VII

they had to be cut down to fit the plate holder. This had to be done in total darkness using a special jig made up for the purpose (see plate VII). With great care about 80% success could be achieved using this apparatus. After exposure the plates were developed in Kodak metol-hydroquinone developer D19b for 5 minutes at $68^{\circ}F$, then washed, fixed and dried in the usual way. For photometric work it is desirable that the plates should be brush developed. This was not possible as the size of the plates prevented them from being held firmly enough, particularly when a number of plates had to be treated identically so that they could be compared.

A perspex tray was made with twelve slots roughly the size of the plates into which they could be put and the tray handled as one unit. Uniform development was thus ensured and the developer was continually moved over the plates to produce as good an approximation to brush development as possible.

This method of treating the plates reduced but did not eliminate the handling which they inevitably received when being cut, loaded, and developed. Their small size made it particularly difficult to prevent contamination especially when working in the dark. Great care was also required to prevent pieces of dust and glass chips in the plate holder and irregular/

irregular edges on the emulsions from holding the plate slightly out of position and so producing an out-of-focus image.

To make an exposure the following procedure is used. First some plates are cut, put into light-tight boxes, taken to the hut and loaded into the plate holders in the dark-room there. Before inserting the plate holders into the spectrograph the following adjustments have to be made. The box is removed and the grating angle and slit opening set, the grating and the mirror being uncovered. The box is then replaced, the slit shutter connected and set with the step reducer in position and the cloth cover replaced over the external lens support. The plate holder is put into the camera and the instrument is ready for an exposure. It is then wheeled out of the hut, pointed at the appropriate area of the sky and the shutter opened. When the exposure is complete the shutter is closed and the instrument turned round to face the hut to receive the light from the copper arc on the optical bench. A piece of ground glass is placed in front of the slit to ensure uniform illumination. The slit shutter position is then changed so that the upper $\frac{1}{4}$" is open and an exposure to the copper arc is made for one minute. The plate holder is taken out of the camera, the plate put into a light-tight box, and taken to the dark room for development and subsequent examination.

III./

III. EXPERIMENTAL PROCEDURE USED IN PREPARING THE SPECTROGRAPH

The spectrograph had been used by the Americans before it was sent to this country but was dismantled for transport across the Atlantic. Thus when work was started the base board still showed the marks where the components had previously been mounted; but apart from this and a rough sketch of the layout no instructions were received.

The base board was examined and because of the damage it had received it was considered advisable not to use it but to rebuild the instrument on a new board. A $\frac{3}{4}$" piece of block-board of the correct size was purchased and the lay-out of the instrument copied on to it from the old board. The components were placed on these markings and temporarily secured. Using visual methods the following settings were obtained:

(1) Prism and slit set perpendicular to axis of mirror.

(2) Slit at focus of collimator mirror - checked by small telescope set for infinity.

(3) Centre of mirror, centre of grating and centre of reflecting face of prism co-linear. These were set approximately on the board, and then more accurately using the adjustments available on each component, in particular those on the prism mounting.

(4) Prism set at same height as centre of mirror.

(5)/

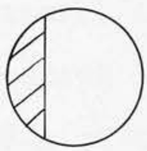
(5) The Schmidt camera position was chosen so that its axis was on a line at 40° from the axis of the collimator in such a position that (a) it did not obscure the beam of light between the collimator and the grating (b) it did not prevent the cover being easily fitted over the instrument i.e. it was not placed too near the edge of the baseboard.

During this process the components were examined and found to be in such a condition that it was necessary to strip them completely except the camera, clean the optics, lubricate the moving parts, reset, repaint and in some cases repair mechanically. When this had been completed satisfactorily the position of prism and slit, collimator and grating were rechecked visually and the components were permanently bolted to the base board. The mirror was then adjusted to throw the beam of light symmetrically on the grating, and the grating itself turned so that the blaze occurred on the correct side and orientated so that the lines were parallel to the slit and the diffracted beam fell symmetrically on the Schmidt.

As the infinity focus of the Schmidt was still uncertain the collimator setting was then checked photographically using a Leica f/2 camera. This position was satisfactory so the Schmidt was painted and mounted, and its focus position was found/

found visually.

Up till this point the source of light used to illuminate the slit had not always filled the optics. A Kodak Aero-Ektar lens was held in a clamp so that it focussed a beam of light on to the slit. When the f number of the lens equalled that of the collimator, the mirror was filled with light. The source used was a high pressure mercury vapour lamp. This gives a very intense light and when it was accurately condensed on to the slit the beam of light within the instrument could be seen. Using this, fine adjustments to the position of the prism were attempted before the Schmidt focus was finally set. The prism was moved so that when the aperture of the external lens was reduced the small circle of light was thrown centrally on the mirror, and when matched into the mirror the beam was symmetrically placed. However, no matter how the prism was positioned it was found that the circle of light on the mirror at full aperture was never uniform in illumination, about $\frac{1}{4}$ of the circle being at about $\frac{1}{4}$ the intensity of the rest, thus:-



LOW INTENSITY REGION SHADED.

The cause of this was found in the fact that not all the light was totally reflected in the prism because the angle of incidence at/

at one side of the fairly wide angle beam became less than the Brewster angle. The only way to correct this defect, which was shown up by the very intense source, was to tilt the axis of slit and prism away from the perpendicular to the axis of the collimator by about 6°. At this angle when the beam was symmetrical on the mirror the line of cut-off of full illumination occurred just off the mirror. The position of slit and prism was therefore changed and they were bolted into this new position and the collimator again checked visually.

Attention was then returned to the Schmidt. To conserve the special spectrographic plates the setting-up exposures were done on strip film cut to the correct size and backed in the plate holder by a piece of glass. When the focal plane was viewed from the rear through the hole in the centre of the mirror two spectra appeared superposed and no position of the camera was found in which this did not occur except when the camera was tilted into a ridiculous angle from its correct position. This ghost spectrum also appeared on plates taken in the camera. It was first thought that the "ghosts" were being produced by reflections from the plate holder support on either side of the plate. This area was painted with black paint but no improvement resulted. The setting of the camera which up till now had been assumed correct, was suspected and the/

the camera was stripped. It was found that the plate holder support had been shimmed out of its original position. These shims were removed and the camera set up as follows. A piece of cardboard with a pin hole was placed centrally over the Schmidt plate and illuminated by a diffuse light. The mirror was then adjusted so that when viewed through the hole at the rear of the camera the reflected image of the pin hole coincided with the pin hole itself. This ensured that the centre of the Schmidt plate was on the axis of the mirror. Using a brighter source the image of the pin hole, as reflected from the two surfaces of the Schmidt plate, was observed as the Schmidt plate was screwed in and out. The best position was judged and the Schmidt plate clamped. This set the corrector plate at the centre of curvature of the mirror. When this was completed the plate-holder was view ed through the rear of the camera and found not to be central relative to the hole. This was investigated and it was found that the hole in the mirror was not central. The whole of the above procedure was repeated this time placing the hole in the mirror centrally with respect to the casing. This setting was found satisfactory.

The Schmidt was replaced on the board and although this position was correct in terms of the external casing this did not necessarily ensure that the optics were correctly aligned. A visual method was used to check this as follows. Using the specular/

specular reflection from the grating the camera was so orientated that the image of the slit viewed in the focal plane fulfilled two conditions:

(1) With a spot source the image was in the centre of the plate with bright rings due to reflection from the lens surfaces symmetrical about it.

(2) With a line source ghost lines appeared symmetrically placed about a line at the centre. These ghost lines are due to the reflections from the lens surfaces and do not appear on the photographic plate unless the intensity is exceptionally bright, which never happens when the instrument is being used to record spectra. Some ghost lines still appeared on the plate, however, and these were traced to:

(1) light being reflected from prism to slit and back again and hence through the instrument: these were removed by cleaning the prism.

(2) light by-passing the slit and falling directly on to the grating and the Schmidt: this was blocked out.

A ghost-free spectrum was then obtained and the Schmidt finally secured to the base board.

The jig mentioned on page 16 , for cutting the plates was made up and found satisfactory. The external lens was mounted on a permanent bracket made for the purpose, and fitted with the slit at its focus. With this in position and using the plates some exposures were made. They were satisfactory and

no/

no other adjustments were attempted until the instrument was finally mounted.

As the mounting of the external lens required two projecting supports which fouled the box a special sliding door was made to slip over these and to accomodate the shutter. This was not completely light-tight so a curtain of black cloth was made to fit over the lens support.

A naval searchlight mounting was obtained to support the instrument. When it arrived it had a suitable vertical bearing but the arms which had held the searchlight had no horizontal bearing and were too narrow to accomodate the instrument. Using the Observatory workshop facilities these arms were widened and plumber blocks fitted on to their ends. A cradle was made up of angle iron to support the instrument and this was slung between the arms by means of two short pieces of shafting on to which two other plumber blocks were clamped. Thus a horizontal bearing was p rovided. The position of this was controlled by a worm and wheel drive, the worm being bolted on to one arm and the wheel pinned on the shaft. The original base board was fixed to this cradle and the instrument bolted on to this board. In order that the instrument could be pointed at the zenith the axis of the external lens was mounted at right angles to the horizontal bearing/

bearing i.e. the instrument was off-set on the cradle by 6°.

Instead of placing the instrument and its mounting in a permanent position in the open where it would be difficult to make any adjustments in bad weather it was decided to place it on rails so that it could be moved in and out of the hut. This necessitated the construction of a wheeled trolley and rails. The trolley was made up of angle iron strips welded so as to form a base for the searchlight mounting. The rails were strips of angle iron bolted inside to the concrete floor of the hut and outside to railway sleepers. Duck boarding was laid round the rails outside to facilitate working after wet weather. The rails stretched 10 feet outside the hut and 7 feet inside. At the same time a dark room was built into the hut for loading the plate holders.

The instrument was mounted on the trolley and tested using an artificial source fitted on the optical bench. The spectra were found to be off centre. The lining up procedure for the Schmidt position described above was repeated and the settings altered to correct for this fault. In the process the edges of the prism were painted black to prevent light which had previously been reflected by them from passing into the Schmidt. The Schmidt focus was then checked photographically and set in the best position. The visual setting was found to be remarkably accurate.

The/

The instrument was then ready to record spectra. Additional provisions still required were:

(1) a method of applying a comparison spectrum for wave-length measurements.

(2) some method of enabling relative intensity measurement to be made.

The standard method of providing a comparison spectrum is to arrange a shutter which allows the light from the comparison source to fall on the plate immediately above and/or below the position of the spectrum under examination. This must be done without altering any of the settings in the instrument or errors will be introduced. Provision had been made in the slit mechanism for such a shutter to be fitted horizontally. A thin strip of brass with rectangular holes at suitable heights was made which could be slipped into position. This shutter was found to work successfully but because of its horizontal movement it could not easily be operated from outside the box. A shutter with a vertical movement would have been much easier to operate and alterations to accomodate this were made. The shutter (see plate V) was fitted immediately in front of the slit. This has two positions (as described on page 8). The comparison spectrum was only placed on one side of the unknown spectrum as it was thought desirable to leave/

leave as large an opening as possible for the spectrum under examination. The comparison source chosen was a copper arc as it gives a spectrum with a large number of lines over a wide wavelength region from the ultra- violet to the infra-red. A D.C. power pack was made to run this arc using at mains voltage a full-wave rectifier smoothed by a 60μF condenser and a low resistance, high impedance choke. This provided light of sufficient intensity to give a reasonably exposed spectrum within 1 minute. The beam of light was collimated by placing a large condenser lens on the optical bench at its focal distance from the arc. This beam fell directly on to the external lens. A piece of ground glass was, however, required to ensure uniform illumination.

The standard method of enabling relative intensity measurements to be made on a spectrum is to provide on the same plate as the spectrum, and preferably with the same exposure time, another continuous or line spectrum the intensities of which are reduced in steps of known ratios in a direction at right angles to the dispersion. These steps are produced by using a step reducer or a rotating sector the function of both of which is identical; the first reducing the intensities in the ratio of the transmission of the various thin layers of metal evaporated on to it, the second by reducing the intensities in the ratios of the size of the sectors cut out of

a/

a disc which is made to rotate in front of the slit. From this second spectrum the characteristic curve of the plate i.e. plot of log (relative intensity) against microphotometer deflection can be constructed at any wavelength and so the relative intensity of any given line found after it has been measured with a microphotometer. Unfortunately with this instrument there is no room on the plate to put such an additional spectrum and so some other method had to be devised. The solution of this problem was to place in front of the slit a step reducer so that all the light coming from the source under examination passes through it and the lines of the resulting spectrum are themselves stepped and so measurements on them can be used to construct the characteristic curves.

The exact position in which to put the step reducer was not known at first, so using a photographic copy of a step reducer kindly lent by Dr. Ellison of the Royal Observatory, Edinburgh, various positions were tried. This copy did not have a very wide range of intensities and so the steps on the spectra produced were not very clear. It was finally decided that the best position was immediately in front of the slit and as close to it as possible. The characteristic of a suitable step were worked out and enquiries about it were made at Hilger and Watts. They reported that one could be made to our specifications but only after a delay of at least nine/

nine months. As results were required as soon as possible it was decided to try to make a step reducer using the evaporation plant in the Observatory.

The first requirement was a piece of quartz on to which to evaporate the steps. A suitable piece was found by stripping a radio oscillator crystal. This had a rough surface and had to be ground flat. To do this the piece of quartz was set in plaster-of-Paris and ground first with corundum powder and then rouge against a pitch base which was rotated in a lathe. When the surfaces were sufficiently good the quartz strip which measured approximately $\frac{3}{4}$" x $\frac{1}{4}$" x $\frac{1}{16}$" was taken out of the plaster and cleaned.

The best materials for making the translucent steps are either platinum or rodium as these give neutral filters i.e. the transmission is constant with wavelength. Unfortunately these alloy with all the materials that were available for making heating filaments for the evaporation plant. It was discovered, however, that chromium, which could be evaporated, reputedly gave a neutral film and it was decided to use this metal. Some pure chromium was obtained and the evaporation plant set up. Using two razor blades to define the free target area of the strip this was evaporated on to the quartz. When one evaporation was complete the vacuum was broken and the razor blades moved - each time the target being decreased by/

by $\frac{1}{8}$". This was done four times. The resulting step reducer had one step clear quartz and four others with increasing density. It was not possible to control accurately the amount of chromium evaporated each time - it was in fact done by selecting a small piece of chromium which appeared to be of the correct size. Thus although there was enough space for five steps in addition to the clear step, by the time four had been made the range of transmissions thought adequate had been covered. The densest step is therefore twice as broad as the others.

The completed step reducer was then mounted into the shutter mechanism (see plate V). It was secured in the $\frac{3}{4}$" gap with the coated surface nearer the slit, mounted in a very fine strip-brass support. This ensured that the vulnerable coated surface was not damaged by contact with the slit jaws.

Spectra were taken with the step reducer in position but instead of showing clear-cut edges between each step the intensity seemed to fall off gradually. The cause of this fuzziness was found to be overlapping of two images of the step. The two images showed up very clearly when a narrow strip of the slit was defined by two razor blades stuck on to slit jaws. This double image persisted in spite of many attempts to find out its cause. One suggestion was that multiple reflections were occurring in the Schmidt. To check this/

this the grating was tilted vertically so that the light was entering it at an angle. This did not affect the double image as might have been expected if it had been due to reflections within the Schmidt. It was found possible to remove one of the images by reducing the aperture of the external lens or by covering about half of the Schmidt plate. It was suggested that the trouble might be astigmatism in the collimator and by placing the step not exactly at the slit it might be possible to find a position where both were in focus. This was tried, defining a small strip of the slit by razor blades held at different distances from the slit. This led to no improvement. The Schmidt camera had been found sensitive to angular displacements from its best position in the horizontal plane - it was thought that similar displacements in the vertical might affect the image. But no improvement could be made here.

It was finally decided to do a Ronchi test on the collimator using the ten-inch Newtonian telescope which is set up in the same hut as the instrument. The instrument was placed in a position where the telescope could receive all the light from the collimator. The grating was removed and the light from the mercury lamp condensed on to the Ronchi disc which was fixed on to the slit. The telescope was focussed for infinity and so the image of the Ronchi disc as seen in it should have been sharp. This was not found to be so until the collimator had been/

been moved about $\frac{1}{16}$" nearer the slit. The Ronchi disc was replaced by the step and the setting checked. A small theodolite telescope was used in the initial setting up, but this was not nearly sensitive enough to check that the slit was exactly at the focus of the collimatror. The larger diametrer and magnification of the Newtonian telescope were required before this could be satisfactorily set. When the step and slit were in focus the collimator was clamped. A spectrum was taken and found to be out of focus but after the Schmidt focus had been set visually a clear step spectrum was obtained. The instrument was replaced on the rails and the optics finally checked. The top of the prism was made horizontal, the grating was removed and cleaned with ethyl alcohol. It was then replaced and checked so that (1) the height of the shadow of the prism was the same before and after reflection at the grating (2) light fell centrally on the grating (3) light fell centrally on the Schmidt plate. This last conflicted with setting (1) and in order to improve (3) the Schmidt was raised on a $\frac{1}{8}$" thick plate. The light was then passing through the instrument always at the same height i.e. it remained horizontal. The focus of the Schmidt was then checked photographically and set at the best value. The angular position was checked in the same way as described on page 23

The comparison spectrum was investigated, the grating settings/

settings giving the different orders found and some of the more intense lines identified. More accurate identification was left until the plates could be measured on a microphotometer. The results of these measurements are given at the end of Section IV along with the results of the auroral and night air-glow spectra.

The spectrograph was then ready to record auroral spectra and to obtain from the exposures the maximum amount of information.

The setting up procedure described above was at times slow, trial and error methods being occasionally required to find the answer to a particular problem. In the light of the experience gained the following procedure would be adopted if the same task were again to be tackled.

(1) Draw an outline of the components on a base board and place the slit, prism and collimator on it.

(2) Arrange for an intense source to be condensed on to the slit and using the resulting bright beam check that the collimator is filled with light. If required alter the position of the slit and prism to obtain this condition.

(3) Adjust the prism so that light falls symmetrically on the mirror when the top surface of the prism is horizontal.

(4) Using a Ronchi disc and a telescope with diameter as large/

large as the mirror, position the collimator so that the slit is accurately at its focus. If a suitable telescope is not available a plane mirror could be used to reflect the beam from the collimator back so that the returning beam would be brought to a focus near the slit. By moving the collimator the image of the Ronchi disc at the slit could be made to coincide with the disc itself. In this position the slit is at the focus of the mirror.

(5) Mount the grating on the board and adjust the collimator so that the light from it falls symmetrically on the grating when the blaze is set correctly and the lines of the grating are parallel to the slit.

(6) Set the grating so that the shadow of the prism is at the same height before and after reflection.

(7) Check the internal settings of Schmidt as described on page 23 and mount it on the board. Then align the axis of the camera so that when there is a line in the middle of the photographic plate the reflections from the faces of the field flattener lens are symmetrical about it. The ghosts due to misalignment will then be minimal.

(8) Check the Schmidt focus visually, then photographically.

(9) Make provision for the application of a comparison spectrum/

spectrum and the positioning of a step reducer at the slit.

IV. EXPOSURES MADE WITH THE SPECTROGRAPH AND THE RESULTS OBTAINED FROM THEM

(1) (a) Exposures on the Aurora and the Night Airglow.

Although the spectrograph was in a condition to record spectra from a laboratory source the best settings for auroral exposures was not known. Up till Christmas 1955 no auroral activity had been observed although a watch had been kept on every clear night during the previous winter months.

The first observable display occurred on January 18th 1956. This took the form of a low intensity glow. An exposure was made on this with the slit set at the same opening as had previously been used for the artificial sources i.e. 50μ. It was hoped at this point to map out the auroral spectrum in terms of the brightest lines so, in order to cover the maximum range of wavelength on one exposure the grating was set to record the first order spectrum in the camera. Unfortunately no lines were found on the plates after development. This was thought to be due to:

(1) using first order spectrum away from the blaze region.

(2) too narrow a slit.

(3)/

(3) low intensity of source.

The next observable display occurred on 10th March. This was a brighter display reaching class II intensity at times.* An exposure was made for 1½ hours before cloud and ground mist obscured the sky. The slit for this exposure had been increased to 100μ and the wavelength region covered being centred on 5500 Å in the second order. When the plate had been developed it showed the two most prominent lines in the spectrum namely those at 5577 and 6300 Å and nothing more. Since the first exposure the step reducer had been fitted to the instrument but the images of these two lines were obtained only through two steps.

This plate showed much less than had been anticipated and in order to increase the amount of light reaching the plate to a maximum two further modifications were made to the instrument.

(1) A series of spectra of the copper arc were taken with the slit set at 50, 100, 150, 200, 300, 400, and 500μ. These were examined to see which setting gave the brightest lines without noticeable loss of resolution. 200μ was chosen as the most suitable and this setting was used for all other exposures for wavelength measurements.

(2)/

* The classification of the intensity of auroral displays is made roughly under four headings: I. Weak - like Milky Way II. Moderate - like moonlit cirrus III. Bright - like moonlit cumulus IV. Brilliant.

(2) The external lens was removed. As mentioned on page 24 the lens serves no useful purpose for low intensity aurora and does cut down the light entering the instrument. When exposures were first made without the lens the plates were found to be badly fogged. This was due to light entering the instrument obliquely, by-passing the slit and falling on to the camera. To prevent this a shield with a hole at the level of the slit was made up of sheet aluminium painted black, and fitted between the slit and the shutter on the side of the box. This ensured that all light entering the instrument passed through the slit. An exposure was made and the plate was found to be free of fog.

Near the blaze angle the third order in the blue at about 3600Å overlaps the second order at 5500Å. As there are a number of strong emissions in the auroral spectrum in both these regions it was necessary to block out the blue with a filter. The one chosen was a Wratten No.3 filter which has a transmission of approximately 90% above 4800Å and cuts off all wavelengths below this. It was much more difficult to find a blue filter which would pass the third order lines while blocking the second order. All those available had a comparatively short transmission region and even then their peak transmission was never better than 60%. This loss of light/

light appeared inevitable until it was discovered that the 103a-O plates had a sharp cut-off of sensitivity above 5000Å and so would not record the second order lines. They could therefore be used to record the third order lines without a filter.

In order to cover, without overlapping, the range of wavelengths where the photographic plates were most sensitive two positions of the grating were chosen.

(1) With the grating scale at 17 a range of wavelength in the second order from 3,600 - 5100Å was covered. Using the O type plates no filter is required.

(2) With the grating scale at 22½ the range 5,000 - 6,400Å in the second order was covered; the yellow No.3 filter being required with the F type plates. Using the O-type plates with the same setting and no filter the third order blue from 3,500 - 4,500Å was covered.

The next observable auroral display occurred on 30th March. This was a low intensity class I glow. With the slit set at 200μ, the grating at 22½ and using the yellow filter (i.e. position (2) above) an exposure was made for one hour. This showed the red and green lines of the spectra but nothing else. As the auroral intensity was low this was a distinct improvement on the previous exposures.

Three/

Three days later there was another display. Using the settings for the blue region of the second order (see (1) above) an exposure was made for $1\frac{1}{2}$ hours. Unfortunately this display was very weak and largely obscured by cloud and ground mist and very little appeared on the plate.

On 16th April an opportunity arose to use the same settings on a class II display. The exposure was made from 22.20 hrs. - 01.00 hrs. Seven lines and bands appeared on this plate which was the best result achieved with the aurora.

There was no further observable activity until May 16th. Then there was an interesting display of an arc with rays and at times a pulsating surface. The intensity however was never very great and with an exposure from 01.15 - 02.15 hrs. only the red and green lines appeared. However four steps were seen in this case.

On the whole the winter 1955-56 has been very poor for aurora. The six auroral exposures made showed, in all, only nine lines and bands in the range 3,600 - 6400Å (see sect. ii below on page 44). The frequency of occurrence was much lower than anticipated from the sun-spot cycle and such displays as did occur were of low intensity - no display of intensity greater than class II was observed.

In addition a recurrent period of solar activity coincided with/

Checked

with full moon. A number of displays were observed in bright moonlight, but these could not be recorded with the instrument because the moonlight would have masked the auroral spectrum over the long exposures required. The results obtained do, however, show the capabilities of the instrument. These will be discussed in the Conclusion (see page 72).

As the intensity of the night airglow is so much less than that of the aurora very much longer exposures are required before a measurable spectrum is obtained - in fact the plate must be exposed for a number of nights in succession. Up till the end of March no attempt had been made to obtain airglow spectra because auroral exposures had priority and it is impossible to replace a plate which has been removed from the instrument for any reason. Thus as the probability of auroral activity was still appreciable the possibility of obtaining a full uninterrupted airglow exposure over a number of nights was not very high. After the seasonal maximum for auroral activity had passed in March it was considered desirable in view of the small number of results obtained from the aurora to turn attention wherever possible to the airglow. Therefore on the night of 1st April an exposure was made for 4 hours with the instrument pointing approximately at Polaris and set for the second order blue region. An auroral display did/

did occur the next night terminating the exposure prematurely. The plate was developed and two lines were just discernable on it. The slit for the airglow exposures was set at 500 μ as it was thought preferable to sacrifice a little resolution for the possibility of greater intensity.

The night of 3rd April was again clear and an exposure of $4\frac{1}{4}$ hours was made on another plate with the same settings. The following night it was possible to expose for a further hour before cloud obscured the sky. The cloudy weather persisted for six nights but on 11th April a further exposure was made bringing the total up to $9\frac{1}{4}$ hours. This exposure was not extended any further as it was not known if the box was sufficiently light tight to prevent fogging over such a long period. The plate although free of fog showed very little more than the previous one which had had half the exposure time. This was thought to be due to the fact that sky conditions during the second exposure were not always very good - the exposure being thus effectively cut down.

About this time attempts were made to obtain spectra of the special effects that occur at twilight. These proved to be successful and after the end of April apart from keeping a watch for aurora, attention was turned exclusively to this study. The twilight had the great advantage that spectra could be obtained from it in a matter of minutes as compared with/

with the several nights required for the night airglow. More use could therefore be made of the time available for observations. The importance of this is emphasised by the fact that in April, due to cloud conditions and the presence of the moon, there were only seven nights when observations were possible.

During the April full moon period the auroral and airglow plates obtained by then were taken to Edinburgh and microphotometered using the recording instrument at the Royal Observatory. It had been hoped to obtain accurate wavelength measurements from these traces but this was not possible for the following reasons:

(1) the length of the spectral lines both of the comparison and the auroral spectra were too short to enable the instrument to be accurately lined up on the spectra. This defect will be discussed in the conclusion (see page 70).

(2) the sensitivity of the instrument was greatly reduced by a uniform background fog. The importance of this fog had not been realised before as it had been present on all the plates used with the instrument. It was first thought to be due to chemical action produced by an inappropriate developer. A fresh piece of plate was taken straight from the box of unused plates and developed in a different developer. This showed the same fogging, indicating that the plates themselves were/

were at fault. These plates had been sent over from America with the instrument some 18 months before and it must be assumed that at some time during their transport they were damaged so causing this fogging. Fortunately it was possible to obtain replacements almost immediately which, when used on the subsequent investigation of the twilight effects, gave excellent results. The night airglow spectra obtained showed only two lines but as with the aurora these do show the capabilities of the instrument in this field. (see page 73).

(1) (b) Results obtained from the measurement of the Auroral and Airglow spectra

For the reasons given above accurate wavelength measurements have not been attempted; the lines and bands appearing on the plates have merely been identified. They are all assumed to be features which have appeared in spectra obtained by other investigators and their approximate wavelengths have been checked against previously published lists.[6,7,8]

Aurora		Date of commencement and duration of exposure	Intensity class of aurora	Wavelength region	Wavelength Å of lines and bands found	Probable source
	1.	10th March $1\frac{1}{2}$ hrs.	II)		5577	OI) Forbidden
	2.	30th March 1 hr.	I)	5000 - 6400	6300	OI) transitions
	3.	16th May 1 hr.	II)			
	4.	2nd April $1\frac{1}{2}$ hrs.	II	3600 - 5100	3914	N_2 band-negative group
					4368	OI line-faint & uncertain
	5.	16th April $1\frac{1}{2}$ hrs.	II	3600 - 5100	3914	N_2 band-negative group
					4058	" " -2nd positive group
					4236	" " -negative group
					4278	" " - " "
					4368	OI line-faint & uncertain
					4652	N_2 band-negative group
					4709	" " - " "
Night Air-glow.	6.	1st April 4 hrs.		3600 - 5100	4048	Uncertain-either N_2 Vegard-Kaplan band
	7.	3rd April $9\frac{1}{2}$ hrs. (to 11th April)		" "	4368	OI line or O_2 Herzberg band.

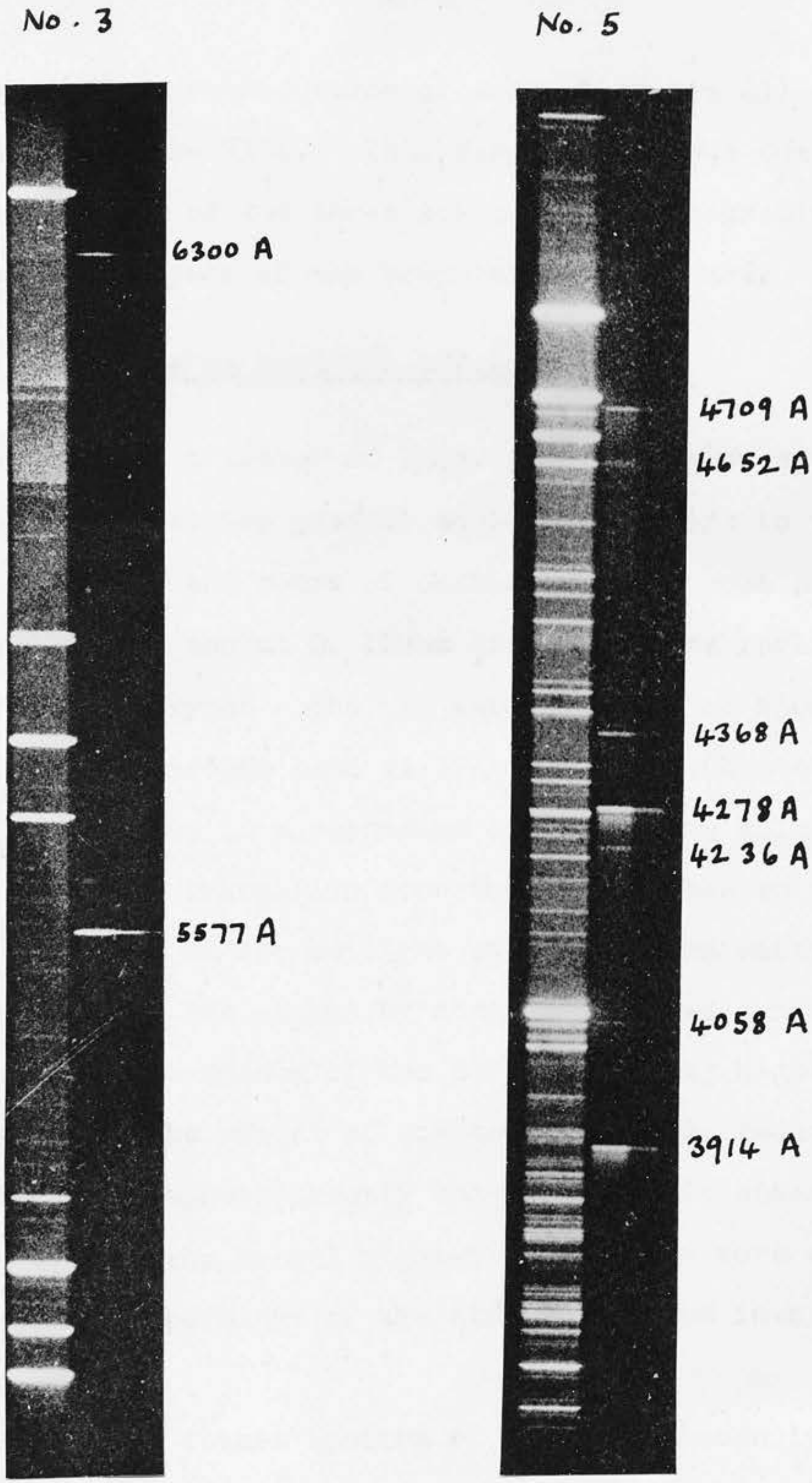

No. 3
No. 5
6300 A
5577 A
4709 A
4652 A
4368 A
4278 A
4236 A
4058 A
3914 A

PLATE VIII

An enlarged reproduction of auroral plates (3) and (5) are shown on plate VIII. (VIIIa) This plate also shows the comparison spectra for each of the three positions of the grating used with the wavelengths of the brighter lines marked.

(2) (a) Exposures on Twilight Effects.

At twilight a number of lines in the airglow spectrum have their intensities greatly enhanced relative to the values they have during the hours of darkness. The most prominent of these are the sodium D. lines at 5894 Å, the forbidden transitions of oxygen - the red auroral lines at 6300 and 6363 Å, and a nitrogen band at 3914 Å. The enhancement of these lines is due to a resonance effect of the solar radiation and it marks the transition from the day airglow to night airglow. Normally before twilight the radiations emitted by the upper atmosphere are masked by strong scattered sunlight. At twilight when the shadow of the earth is moving higher into the atmosphere the amount of scattered light is reduced and these emissions appear greatly enhanced. This enhancement is soon reduced to the normal night-time level as more and more of the emitting portions of the atmosphere pass into the earth's shadow.

In order to obtain spectra of this phenomenon it was first/

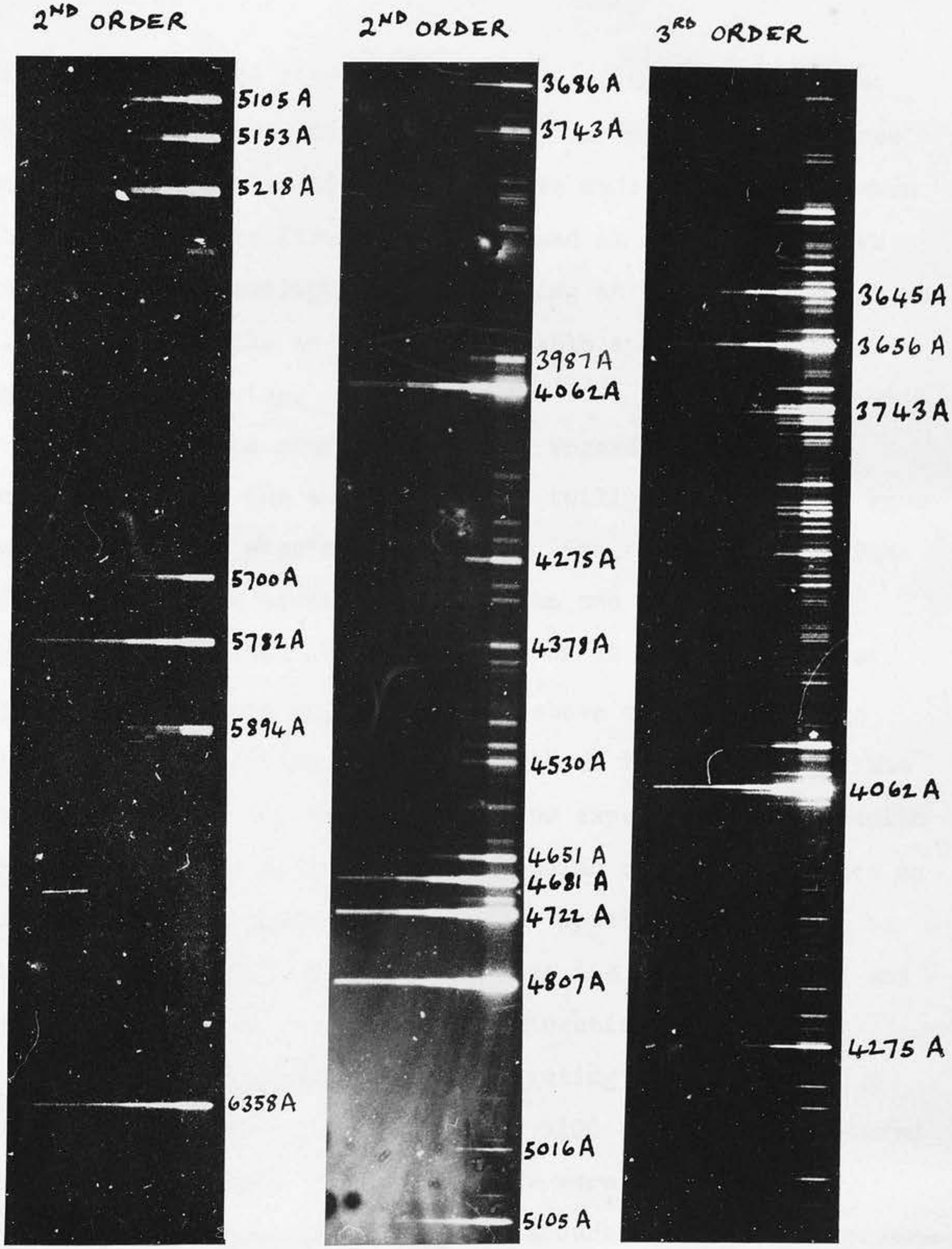

2ND ORDER
5105 A
5153 A
5218 A
5700 A
5782 A
5894 A
6358 A
2ND ORDER
3686 A
3743 A
3987 A
4062 A
4275 A
4378 A
4530 A
4651 A
4681 A
4722 A
4807 A
5016 A
5105 A
3RD ORDER
3645 A
3656 A
3743 A
4062 A
4275 A

PLATE VIII a

first necessary to find appropriate starting times for the exposures. At the end of April, and during the first three days of May a number of exposures were made and the time when the enhanced lines first appeared fixed at about 20 minutes before nautical twilight when observing at the zenith. It was also found possible to obtain measurable spectra with an exposure of 10 minutes.

Following the procedure used by Vegard[9] for the investigation of the sodium lines at twilight a series of runs were made on the evenings of the 3rd, 5th, 6th, 8th, and 9th of May and on the mornings of the 12th and 13th. Each of these runs consisted of a succession of 10 minute exposures, first at the zenith and then at 15° above the horizon in a direction approximating to the azimuth of the sun at the time of the middle of the run. After four exposures at the zenith the intensity had fallen below that which could be recorded on the plate in 10 minutes. Measurable spectra could still be obtained, however, near the horizon as the earth's shadow was not at such a great height in that direction.

These runs were made with the grating set at 22 i.e. a range of wavelength of approximately 5100 - 6500 Å was covered in the second order. As the spectra were to be used for intensity meas urements and not for accurate wavelength measurements/

ments the slit was increased to 500μ to ensure that the maximum amount of light reached the plate.

The auroral exposures had proved unsatisfactory for any investigation of the temperature of the upper atmosphere using the profiles of the nitrogen bands (see introduction). It was hoped however that the bands enhanced at twilight would be amenable to this analysis. It was with this in mind that, after visual examination of plates of the first ten runs had showed that they contained the information which had been expected; that on the evenings of 12th, 13th and 14th and the morning of 15th May a number of runs were made using the third order blue region. This region of wavelength from 3,500 - 4,500 Å was selected as indicated on page 38 above, the greater dispersion of the third order being an advantage for this investigation. The length and timing of these exposures was somewhat different from that for the earlier runs. Also as resolution was of importance the slit was reduced to 200μ for the later exposures once their timing had been established, Full details of the exposures giving measurable plates are listed below.

In addition to these runs an exposure was made during the night of 12-13th May on the night airglow for about 2¼ hours covering the period round midnight between evening and morning twilight. As astronomical twilight persists throughout the night/

night at this time of the year this has not been included in section IV (1) above as the spectrum is as much that of the twilight as of the night airglow.

As these plates were to be used for intensity measurements it was essential that all those of one run should be developed identically. This was done using the developer tray mentioned on page 16. The lines of the spectrum appeared only through one or at the most two steps of the step-reducer so that a copper arc spectrum exposed through all the steps was included with each run to enable the characteristic curve to be plotted for each run at or near the appropriate wavelength.

These plates were taken to Edinburgh and microphotometered during the last fortnight in May as by then observations were no longer worth while due to the shortness of the nights and the interference of the moon. Surface stains found on them were removed with a citric acid cleaning solution prior to measurement.

(2) (b) Results of the twilight exposures and their analysis.

The lines found on the plate covering the range 5100 - 6500 Å were identified as

5577 Å)
6300 Å) The auroral green and red lines of the
6363 Å) forbidden transitions of oxygen.

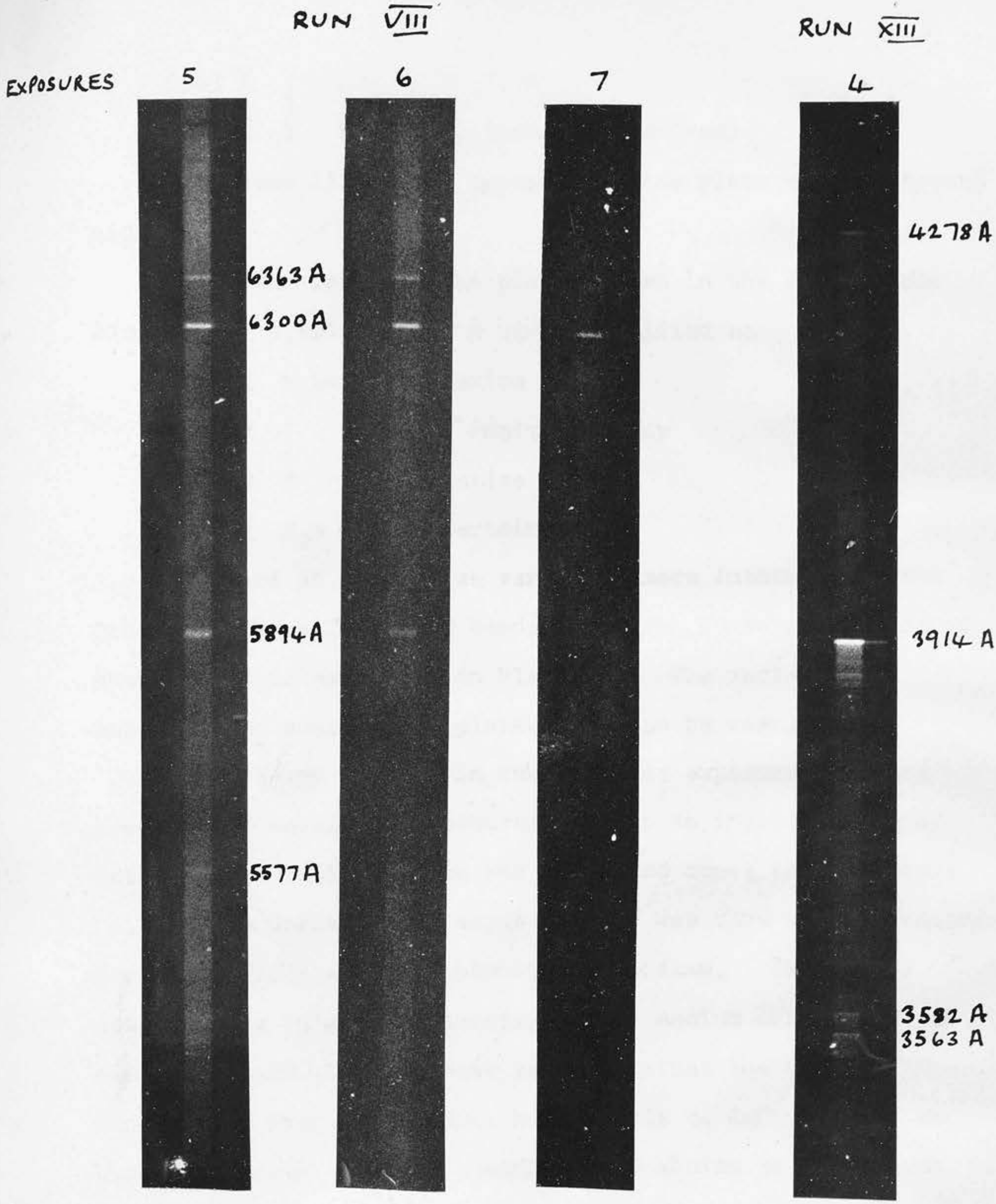

RUN VIII
RUN XIII
EXPOSURES
5
6
7
4
6363 A
6300 A
5894 A
5577 A
4278 A
3914 A
3582 A
3563 A

PLATE IX

6363 Å)
5894 Å) Sodium D. lines (unresolved)

All these lines also appeared on the plate exposed around midnight.

The bands found on the plates taken in the third order blue region 3,500 - 4,500 Å were identified as

4278 Å N_2band - negative group
4089 Å " " - 2nd Positive group
3582 Å " " - negative group
3563 Å N_2+ " - Uncertain.

The band at 3914 Å was very much more intense than the others. These lines and bands are shown in reproductions of characteristic exposures on Plate IX. The variation of intensity on consecutive plates can also be seen.

The primary purpose in taking these exposures was not however the wavelength measurements but an investigation of intensity variations. As was mentioned above the procedure followed in making these exposure runs was that used by Vegard[9] for his investigation of atmospheric sodium. In this he measured the relative intensity of the sodium lines found on his plates and plotted these values against the time of the exposure. From these plots he was able to define times at which there was a sharp cut-off of the sodium emission both when/

when observing at the zenith and towards the horizon. A simple calculation from these gave the height and extent of a layer of the atmosphere which he had postulated as the source of this radiation. In order to ascertain if the same deduction could be made from the results of the exposures made on the twilight with this instrument the relative intensities of the sodium lines were calculated from the microphotometer traces.

First the plates had to be calibrated. Instead of doing this as is usual in terms of the photographic density - $\log_{10} \frac{1}{T}$ where T is the transparency of the plate, the function $\Delta = \log_{10}(\frac{1-T}{T})$ was used. This method devised by Dr. Baker[10] of the Royal Observatory, Edinburgh has the great advantage that the characteristic curve of the plate is linear i.e. the plot of Δ against $\log_{10}$(Relative Intensity) is a straight line. For very accurate work small corrections are required modifying this general statement but these were not necessary for this investigation as the errors otherwise involved are larger than the corrections.

In order to construct the characteristic curve of the plate the transmissions of the steps of the step-reducer are required. These were measured using the microphotometer - the deflection being noted for each step and these values converted into/

into percentages in terms of the clear step, the transmission of which was taken as 100%. When the step-reducer was made it was thought that the transmission of chromium was constant with wavelength. This was checked and unfortunately found not to be true. The step-reducer was therefore calibrated for four different wavelength regions:

(1) About 7000 Å. The microphotometer was used with a thermocouple as the detecting device. This is sensitive to the infra-red and so the transmissions measured are for a region at about 7000 Å.

(2) About 6,200 Å. The thermocouple was replaced with a photomultiplier and used with a Wratten filter no. 22. This passes wavelengths above 6,000 Å but as the photomultiplier is not very sensitive in the red the mean wavelength for which the transmissions were measured is about 6,200 Å.

(3) About 5,300 Å. The filter was changed to a Wratten No. 74. This passes a band with peak transmission about 5,300 Å.

(4) About 4,400 Å. A Wratten filter No. 47B was used. This passes a narrow band with peak transmission at 4,400 Å.

The values obtained for the percentage transmissions were plotted at these wavelengths and the points joined as shown in Graph I to form the curve showing the relationship of transmission/

mission of the steps to wavelength. The values at particular wavelengths were taken from this graph and used to construct the characteristic curves of the plates at the wavelengths.

Each run included an exposure of the copper arc or mercury lamp spectrum for calibration purposes. These were next measured and Δ calculated for each step of each of the brightest lines near the wavelength of the enhanced lines in the twilight spectra. A logarithmic relative intensity ($\log_{10}I$) scale was constructed from the logarithm of the percentage transmission of the steps and Δ for each step plotted against the corresponding $\log_{10}I$ value. Thus for each run several graphs were drawn, one for each line which had meas ureable steps. These graphs were found to be parallel straight lines i.e. the slope of the characteristic curve was constant with wavelength but it did vary from run to run. The zero of the intensity scale is arbitrary. Therefore since the lines are parallel, one curve could be drawn for each run which could be used for all wavelengths. It was found that when a line was just visible above the background grain of the plate its Δ value was $\bar{2}.600$. Consequently the zero of the intensity scale was chosen for convenience so that $\log_{10}I = 0$ when $\Delta = \bar{2}.600$. Graph 2 from Run IX is shown as an example of this.

Having constructed the characteristic curves for each of the runs the intensities of the sodium D lines appearing on the twilight/

twilight exposures were then measured from the microphotometer traces as follows.

(1) The microphotometer deflections for clear plate and infinite blackening on the plate were noted.

(2) The deflection at the maximum of the line was measured.

(3) This value was corrected for the infinity level i.e. the maximum deflection of the line relative to the infinity level was found.

(4) The value of the transparency T of the plate at the maximum of the line was calculated from:

$T = \frac{\text{Max. deflection of the line}}{\text{Clear plate deflection}}$, when both are corrected so that infinity level = 0.

(5) Δ was calculated from $\Delta = \log_{10} (\frac{1-T}{T})$.

(6) The value of $\log_{10}I$ corresponding to this value of was obtained from the characteristic curve.

(7) The antilog. of $\log_{10}I$ was found, giving I'. This is a measure of the relative intensity of the line on a scale which has its zero set so that $\log_{10}I = 0$ when $\Delta = \bar{2}.600$. In fact the scale required is one which has I = 0 when $\Delta = \bar{2}.600$. i.e. the intensity of the light falling on the plate which just fails to produce a discernable line is zero. To convert from one scale to the other the value of I' when $\Delta = \bar{2}.600$

(i.e./

~~(i.e. $Log_{10}0 = 1$)~~ must be subtracted from I'.

(8) Unity was therefore subtracted from the value of I', giving I.

This value I for the relative intensity of the line has to be corrected for two factors:

(1) Those spectra obtained at times nearest sunset or sunrise have the emission spectrum superimposed on a strong solar continuum. This continuum must be allowed for.

(2) One of the prominent features of the solar continuum is the strong absorption lines of the sodium doublet. This means that before the sodium lines appear on the plate superimposed on the solar continuum the absorption lines must be filled in. If no account of this were taken the values of the intensity of the lines would be too low. Allowance therefore must also be made for this.

The correction for the solar continuum level was easily made. The relative intensity value for the continuum immediately on either side of the sodium line was calculated in the same way as for the line itself. This value was subtracted from the line intensity i.e. the line intensity was calculated relative to the continuum as zero instead of relative to the clear glass level.

The correction for the solar absorption was more complicated/

? pref

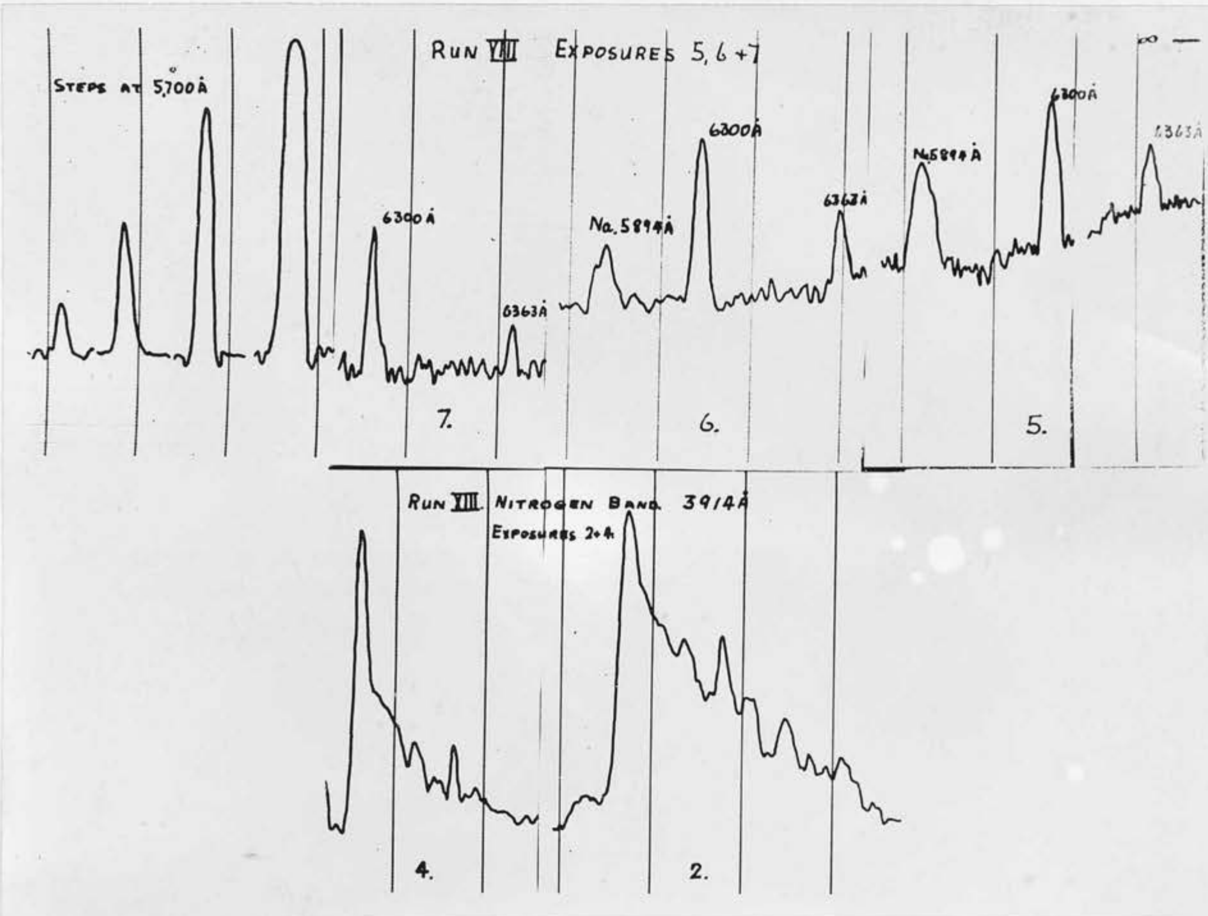
why not

plicated as no spectra were obtained under observing conditions similar to the ones for measurement without the emission lines being present. There are in addition no other comparable absorption lines in the solar continuum present on the spectra in this wavelength region. However, near 4000 Å there are a large number of absorption lines which appeared on the traces of two of the plates taken of the enhancement of the nitrogen band at 3914 Å. From these an estimate of the percentage of the continuum level which must be added to the emission level of a line to allow for the absorption in the continuum was made as follows.

This correction cannot be worked out from a solar atlas for the dispersion is so very different. However, three groups of lines centred at 4,005, 4,030, and 4,046 Å were selected as having a comparable amount of absorption as the region of the sodium lines - these groups of lines being unresolved in the low dispersion spectra taken with this instrument. The relative intensity values of these lines and of the continuum levels immediately beside them were calculated using a characteristic curve constructed for this region. The percentage of the continuum level which each of the peaks of these lines represented, was then worked out. This was done using two spectra which had different continuum intensities but in all six/

six cases the percentage figure was between 14.8 and 13.8%. This was considered sufficiently consistent to permit the value of 14% to be used as an estimate for the absorption of the sodium lines. The correction for the solar absorption was therefore made by adding 14% of the continuum level to the intensity of the line, and a final estimate of the intensities of the sodium lines appearing on the different plates of each of the runs was obtained. The variation of the intensities of the line and of the continuum level is shown in the microphotometer traces of three consecutive exposures of Run VIII which are reproduced in Plate X.

The values obtained for the intensities of the sodium lines were then plotted against time as shown on Graphs 3 and 4. The time scale was chosen with zero at the beginning of each run. As each exposure lasted 10 minutes the mean time i.e. 5 minutes after the start, was taken to represent the exposure. Each run was found to have at most only four exposures with a measurable image of the sodium lines, two at the beginning of those exposures taken pointing at zenith and two at the beginning of the horizon exposures. The number could not be increased as earlier exposures were completely masked by the solar continuum and later ones contained no measurable lines. Each set of two points was joined by a straight line. On/



RUN VIII EXPOSURES 5, 6 + 7
STEPS AT 5700 Å
6300 Å
6363 Å
Na 5894 Å
6300 Å
6363 Å
Na 5894 Å
6300 Å
6363 Å
∞
7.
6.
5.
RUN VIII NITROGEN BAND 3914 Å
EXPOSURES 2+4
4.
2.

PLATE X

On Graph 3 all the results obtained for the zenith exposures are shown together and all those obtained from the horizon exposures are shown on Graph 4. The results obtained during the morning twilight are included along with those from the evening runs. Vegard's graphs had a somewhat different shape from those obtained here - his had more points, the first few being of nearly constant value followed by a very sharp cut-off. The analysis he used to define his cut-off times was tried and found not to give systematic results. Another technique was therefore tried. On both graphs 3 and 4 it was observed that sets which had greatest intensities also had steepest slopes. This was checked by plotting a graph of the mean intensity i.e. the intensity at the time mid-way between the two exposures against the slope of the line. A plot of both the zenith and horizon values combined showed that there is a general linear relation between the mean intensity and the slope. The linearity is much more clearly shown when the two s ets of values are separated (see Graph 5).

The slope $\frac{dI}{dt}$ is known from the graph of intensity against time and if the small intercepts on Graph V are temporarily neglected the straight line relation means that $\frac{dI}{dt} \propto I$

i.e. $\frac{dI}{dt} = KI$ or $\frac{dI}{I} = K\,dt$

$$I = e^{Kt}$$

i.e./

i.e. The intensity of the sodium emission falls off exponentially with time.

More accurately (when the intercepts are included),

$$\frac{dI}{dt} = kI + c \quad = k(I + a) \quad \text{where } a = \frac{c}{k}$$

$$(I + a) = e^{kt}$$

This means that the horizontal asymptote of the exponential is not zero but a. This value of a may be considered as the level of the intensity of the sodium emission throughout the night and agrees very well with the measurement made on an exposure taken for two hours around midnight on 12-13th May.

The intensity I of the sodium emission is proportional to the number N of atoms emitting i.e. $N \propto I$ and the time t at which this number is emitting is proportional to the height h as the time is connected to the height by the motion of the earth's shadow through the atmosphere (see page 62). Thus the results obtained indicate that the number of sodium atoms falls off exponentially with height. This result is in agreement with that obtained by Farnsworth and Elvey[12] from their work in this field.

The other lines appearing on the plates with the sodium lines were next considered. The green auroral line at 5577 Å was too weak to lead to any similar results - it only appeared on/

on one plate of each set. The red auroral lines, however, were much brighter and it was possible to measure them in exactly the same way as the sodium ones except that no allowance had to be made for absorption in the solar continuum. Another difficulty however appeared - the height of the line as recorded on the microphotometer traces was exceptionally sensitive to the position of the plate in the plate-holder. If the plate was for any reason held even very slightly out of focus the measure of the intensity of the line fell sharply. This effect could be detected without much difficulty as when using two plate-holders during the run, alternate exposures appeared to have a much reduced intensity. During the runs the plate-holders were dusted to ensure that nothing was present to keep the plate away from its correct position but subsequent analysis has shown that it was not always possible in the time available to do this with complete success. Fortunately only one plate-holder was affected at a time and never for more than two or three exposures. The effect was much more marked with these single sharp lines than with the broad unresolved sodium doublet and so fewer of these lines were available for analysis. In particular it was not found possible to produce sufficient measures for an analysis of the zenith runs parallel to that of the sodium lines. On the other hand the lines did appear on up to six consecutive plates during the horizon runs and these were amenable/

amenable to analysis.

The values obtained for the intensities of the red auroral lines were plotted against time in the same way as the sodium lines. As the ratio of the intensity of the line at 6300 Å to the intensity of the 6363 Å line was found to be a constant (approximately 3) the results of both could be used. The results obtained for Run IX are shown as an example on Graph 6. An attempt was made to combine the results of the first two exposures of all the runs in terms of the mean intensity and the slope of the line joining them. This proved to be impossible. Each run was however treated separately in this way and a straight line relation was found between the mean intensity and the slope for the points considered in consecutive pairs. e.g. see Graph 6. The asymptotic values obtained for these graphs differed over a wide range and it was for this reason that the results of the separate runs could not be directly combined. These asymptotic values may, however, be considered as the effect of a different process of excitation which occurs throughout the night - possibly the result of the dissociation of O_2 molecules - and may be subtracted from each value to give the value of twilight effect alone. When this was done and the results of the first two points for each run were considered again/

again they were found to fit on to a straight line which had the same slope as each of the graphs constructed for the separate runs, see Graph 7 which is made up of the results obtained in this way from Runs VII, VIII and IX. This w as not necessary with the sodium results as the night level was always such that it did not appear on the plate in ten minutes. This means that when the effect of the night time level is allowed for, exactly the same result was obtained from the analysis of one run - exposures made on one day, as that obtained from the analysis worked out for the combination of results from different runs. From the linear relation between the mean intensity and the slope, following exactly the same argument as for the sodium line results, it can be shown that the number of atoms of oxygen emitting the forbidden red lines decays exponentially with height.

The equivalence of the results obtained on one day to those obtained from the combination of the results of several days is of importance for the conclusions that can be drawn from the results of the sodium measurements discussed above. There, when attempts had been made to find the relationship between the actual time of the exposure relative to sunrise or sunset and the intensity of the lines on the different days of the runs, it was not found possible to obtain agreement with the results of the analysis. i.e. the fainter lines were on occasion found to occur/

occur at times slightly nearer to sunrise and sunset than the brighter ones. This variation is probably due to daily variations in "seeing" conditions in the atmosphere and other influences which cannot be controlled. The results from the measurement of the red lines justify the method of combining the results and enable the effects occurring on one day to be established from measurements taken on a number of different days.

The height of the earth's shadow at times from sunset to midnight above the surface of the earth was calculated for a direction 15° above the horizon and at the zenith for a number of days in the first fortnight in May. The resultant curves (see graph 8) were only linear for the portion of their length between the times of civil and nautical twilights. The times of the exposures made fell within the region and so it is justifiable to take $h \propto t$ as was assumed on page 58. The times of the exposures do also indicate that the height at which the exponential relationship is relevant is between 65 and 85 kms above the earth's surface.

From this analysis it may be concluded that there is a strong indication that the number of atoms emitting the sodium lines and the auroral red lines decays exponentially with height. The implications of this will be discussed in the Conclusion/

Conclusion 3.

Four consecutive plates containing the 3914 Å band of nitrogen obtained during a zenith run were also measured and analysed in exactly the same way as above. The graph of the mean intensity of the line formed from two consecutive points on the intensity time curve, plotted against the slope of this line was again a straight line. The range of time covered by these four exposures was much greater than for the other lines and in consequence the height-time relation of the motion of the earth's shadow was not linear for the whole period. However it may be said that the results indicate that the number of emitting nitrogen molecules also falls off exponentially with height in the range covered i.e. 65 - 100 kms. in this case.

As was mentioned on page 49 these blue plates were exposed for a purpose other than the measurement of their peak intensity - it was hoped that measurements on their profiles might give values of the temperature of the upper atmosphere at different altitudes.

The intensity distribution within the band is controlled by the temperature. In particular, theory predicts that the temperature is connected to the quantum number Km corresponding to the position of maximum intensity in the R- branch by the relation.

T/

$T_m = 2.96$ Km (2Km + 1) $^{\circ}$A.

Thus if Km. can be found T can be calculated. Ten different exposures were microphotometered and the resulting traces examined. The bands were found to have a "head" which had a much greater intensity than the rest. This is the P-branch and stretched out to the short wavelength side of this was the R-branch. The shapes of these were examined and allowing for the non-linearity of the response of the photographic plate they were all essentially the same - see the two profiles on Plate X. This was surprising as it was thought that the temperature and hence the shape would change with height. i.e. with the position of the earth's shadow at the time of the exposure.

The position of the maximum was next examined and found to be very close to the band head, in fact the K value of the maximum could not be greater than 3. This means that the temperature could not be greater than $(2.96 \times 3\ (6 + 1)) = 70^{\circ}$A. This result is a maximum estimate and disagrees strongly with estimates of the temperature of the atmosphere at these heights i.e. about 70 Kms. found by other methods[13] - no value below about 200 Å being accepted as probable anywhere within the atmosphere. This method of estimating the temperature is therefore considered inapplicable.

The/

The quantum mechanical derivation of the formula used is irrefutable; the difficulty arises in the concept of temperature applicable in the context. The temperature derived in this way is called "effective temperature". This does not necessarily bear any relation to the temperature of the gas in which the emitting molecule is situated unless certain conditions are fulfilled. One of the most important of these is that a sufficient time should elapse between excitation and de-excitation so that any energy changes produced in the molecule by the excitation process can be assimilated into the gas as a whole by collision. If this is not fulfilled the "effective Temperature" depends more on the excitation process than the temperature of the gas.

In this case it is a resonance emission that is being studied in an atmosphere at low density and so it is likely that this condition is not fulfilled and the effective temperature can supply no information about the true gas temperature. This will be discussed further in the Conclusion 3.

Details of Exposures of the plates measured

All times quoted are local times, i.e. B.S.T. since 22/4/56.

Date 1956	Run	Slit Width	Starting times of exposures made towards the zenith	Starting times of exposures made towards horizon	Horizon direction	
					From horizon	From North
30th April 2nd May	I, II &III	500	Trial runs no measurements made.			
3rd May	IV	200	21.40 21.50 22.00 hrs.	22.15:22.25:22.35hrs	10°	340°
5th May	V	500	No plates giving measurable results were obtained.			
6th May	VI	500	22.00 22.10 22.20 22.30hrs.	22.40:22.50:23.00: 23.10:23.20:23.30	10°	330°
8th May	VII	500	As for VI	As for VI plus 23.40:23.50hrs.	15°	330°
9th May	VIII	500	As for VI	As for VII	15°	330°
12th May	IX	500	Morning run. No measurable plates.	03.30:o3.20:03.10: 03.00:02.50:02.40hrs	15°	30°
15thMay	X	500	04.00 03.50 03.40 03.20hrs.	03.10:03.00:02.50: 02.40hrs.	15°	30°
14th May	Blue I	500	The traces of these plates were examined but not measured.	The exposure times for all exposures in Runs I to X were 10min.		
15th May	Blue II	500				
16th May	Blue III	200	22.40 23.00 23.30 24.20hrs.	These were consecutive exposures.		

V. CONCLUSIONS

(1) Concerning the working conditions of the instrument and suggesting improvements that could be made.

(a) Grating.

In the description of the Schmidt camera on page 13 the area of the camera aperture from which light is blocked out due to the insufficient height of the grating is given as 2.1 sq. ins.

Now the total area of aperture blocked out = 6.4 sq.ins. and total percentage reduction in light gathering power = 33%

∴ Percentage reduction due to grating size ≒ 10%.

It would therefore be possible to increase the light gathering power of the instrument by 10% using a grating with dimensions at least 5" x 5". As this spectrograph is specially designed for high light gathering power this improvement is worth while and easily implimented if a suitable grating were available. The resulting increase in efficiency might be much greater than this 10% as the surface of any new grating would be much superior to that of the present one.

The loss of light due to the prism is 2-3% and that due to the plate holder approximately 20%. These losses are inherent in the design and cannot be removed.

(b) Blaze angle.

The/

The shape of the grooves in modern gratings is controlled during ruling so as to concentrate a high percentage of the light into a particular wavelength region i.e. the blaze region. This blaze occurs at the wavelength which is diffracted into the same angle as the light specularly reflected from the groove face. The blaze wavelength is not constant but depends on the angle of incidence of the light on the grating. The equations governing this are:

$m\lambda = b(\sin I \pm \sin I')$ where m, , b, I + I' are as

$\phi = I \pm I'$ defined on page

$2\beta = I \mp I'$ ϕ = angle between incident and diffracting beams.

β = blaze angle i.e. angle of groove face to surface of grating.

The lower signs are applicable when I + I' are on different sides of the normal; the upper signs being required when they are on the same side.

Petrie and Small[7] working in Saskatoon with another of the instruments made to Meinel's design report that they had different positions of the camera "so as to work on the blaze in different wavelength regions". Using the values of the parameters for this instrument in the equations it is found that the change in the blaze wavelength is not more than a few hundred angstrom units until the angle is increased to nearly 80°./

80°. At this angle obtained by shifting the camera round on the base board the angle of incidence of the light on the grating is so large that the grating presents a much reduced area to the beam. This reduces the intrinsic intensity of the light on the grating and so that of the light entering the camera which more than compensates for the increase due to working accurately at the blaze. It was therefore considered inadvisable to make any change in the position of the camera with this instrument.

As the instrument has been set up the angle φ is very nearly equal to 2β ($\varphi = 40 \pm 1^\circ$, $\beta = 19^\circ\ 16'$). This means that either I or $I' = 0$ when working at the blaze. As the instrument has been used with $I' = 0$ this had the advantage of giving a linear dispersion as $\frac{d\lambda}{ds} = \frac{b \cos I'}{mf}$ (see page 11). If the grating were turned with the groove face in the opposite direction i.e. so that $I = 0$ the grating would be perpendicular to the beam from the collimator and the intrinsic intensity of the light on it would be a maximum. The camera would then receive a maximum amount of light. Also the value of the plate factor would be decreased by $\cos I'$ i.e. $\cos 40^\circ$ i.e. it would be decreased from 83 Å/mm to $83 \cdot \cos 40^\circ = 64$ Å/mm. These advantages are however offset by the fact that the dispersion is no longer linear, as is seen if the rate of change of the plate/

plate factor with wavelength i.e. $\frac{d}{d\lambda}\left(\frac{d\lambda}{ds}\right)$ is considered.

$$\text{for } \frac{d}{d\lambda}\left(\frac{d}{ds}\right) = \frac{d}{d\lambda}\left(\frac{b\cos I'}{mf}\right)$$

$$= -\frac{b}{fm}\sin I' \cdot \frac{dI'}{d\lambda}$$

$$= -\frac{b}{fm}\sin I' \cdot \frac{m}{b\cos I'}$$

$$= \frac{\tan I'}{f} = -0.0084\ \text{Å/mm/Å}$$

$$\text{as } I' = 40^\circ$$

This means that in a range of wavelength of 1000 Å the plate factor would change by 8.4 Å/mm. Thus careful account would have to be taken of this during wavelength measurements. The choice of the best setting in a particular case will depend on the nature of the investigation.

(c) The Slit and Step reducer.

As was said on page 42 accurate wavelength measurements were not possible because the spectral lines were too short for the microphotometer to be lined up to traverse at right angles to them with sufficient certainty. This difficulty can be overcome by arranging that the comparison spectrum be placed at both sides of the unknown spectrum. This would necessitate alteration of the slit shutter but the length of the slit opening for the unknown spectrum would not need to be altered as the comparison spectrum openings could be halved without preventing/

preventing the spectra from being microphotometered.

The use of the Baker formula for analysis of intensity measurements reduces the necessity of having as many steps as at present. The straight line curve could be defined by two points i.e. by using two steps. The error would be much less if four were used. Four steps with carefully chosen transmissions would enable all but the most accurate photometric work to be adequately tackled. The transmissions that would appear best suited to the type of work done in the investigation are:

(1) clear i.e. 100%

(2) 50%

(3) 25%

(4) 12.5%

With only four steps, the steps would be bigger - an advantage when the plates are being measured in the microphotometer. A step reducer made of some material like platinum or rodium which has, unlike chromium, a truly linear transmission with wavelength would also increase the accuracy of the photometric work.

(2) <u>Concerning the capabilities of the instrument to record auroral and airglow spectra</u>

No exposures were obtained on the aurora or the night airglow/

glow using unfogged plates. If this had been possible more detailed examination would have been carried out. For example Vegard's[14] technique of running the microphotometer across the spectrum along two parallel paths and taking as a line any feature which occurred at exactly identical positions on both traces, might have been attempted. More lines might have been found on the plates than the few that are visible above the fog. This was however not possible nor was it possible to check the validity of this method.

The auroral green line was obtained through four steps in an exposure of 1½ hrs. on a class II display. The transmission of the fourth step is 4% at this wavelength which means that a line of intensity 4 compared to the green line's intensity 100 would have been recorded. In Vegard's[14] tables of auroral lines he quotes the intensities of the lines he has found on this scale. Most of those lines near 5577 Å have intensities 1 - 2 which indicates that the exposure required with this instrument to record the fainter lines of the spectrum would have to be increased by a factor of at least 2. An exposure of about three hours on a class II display should give on an unfogged plate a spectrum showing a number of faint lines.

The performance of the instrument in the blue region of the spectrum seems to be somewhat better due possibly to the O-type plates being more sensitive. A 1½ hrs. exposure in this/

this region on a class II display shows some bands which Vegard has given an intensity value of 2. An exposure of tw o hours in this region on an unfogged plate might therefore give a spectrum containing quite a large number of lines and bands.

With a class III or IV display the exposure time required to give a comparable spectrum might be reduced by a factor of 2 or 3. It is difficult to estimate this, as the intensity classifications are qualitative and no experimental evidence is available on which to base a quantitive judgment. It seems unlikely that it will be possible, as had been hoped, to obtain spectra from particular auroral features as these are rarely sufficiently quiescent to enable a long enough exposure to be made on them unless they are exceptionally bright and the exposure can then be short. Also the area of the sky from which the light is gathered into the instrument is roughly 14° across so making it virtually impossible to state that a particular spectrum comes from a particular feature unless that feature is either isolated or very large.

In an exposure of four hours a spectrum with one line and one band was obtained from the night airglow. Even with unfogged plates it seems likely that exposures of fully twelve hours will be required before a spectrum of many lines and bands can be obtained. The two night airglow exposures were both/

both made in the blue region: the night airglow spectrum appears from the results of other investigators to be brighter in the longer wavelength regions and so shorter exposures might be required for a good spectrum in the yellow-red region.

The intensity of the night airglow is not constant with latitude. Most of the investigators in this field have been working at higher latitudes than St. Andrews where the intensity is greater and so it is interesting that this instrument was able to record as much as it did with the short exposures used.

The performance of the instrument on the twilight phenomena was adequate for the investigation undertaken. More careful timing might enable spectra to be obtained with shorter exposures and so a more detailed picture of the phenomenon built up, particularly with respect to the less intense lines enhanced at twilight.

(3) Conclusions concerning the results of the analysis of the twilight exposures

As was stated on page 62 it may be concluded from the analysis developed for the results of the various lines enhanced at twilight that there is a strong indication that the number of atoms and molecules emitting the sodium D lines, the auroral red lines and the 3914 Å band of nitrogen fall off exponentially with height in a range of heights between 65 and 100/

100 Kms above the earth's surface. This is what is assumed to happen with most of the constituents of the upper atmosphere and supports the results obtained by Farnsworth and Elvey already mentioned. The conclusions reached by Vegard[9] from his analysis of the variation of the intensity of the sodium lines was somewhat different. He postulated that the sodium was confined to a layer between 40 and 110 Kms. above the earth's surface - the boundaries of this layer being fairly well defined. No evidence to support Vegard's postulate was obtained.

The results, however, were all obtained within a short space of time and before any definite picture of the twilight phenomena can be built up a larger body of results will be required. The effects of the seasonal variation of the sun's altitude would have to be investigated together with the shorter term and local variations in the intensity of the emissions themselves. In addition there are a number of assumptions in the development of the argument which would have to be tested. For example the assumption that the time of making the exposure is proportional to the height of the emitting source presupposes that the emission is confined to a narrow layer near the line of the shadow of the earth. This is not strictly correct as the whole atmosphere above the shadow/

shadow line is contributing to the intensity at any given time. Because the intensity may be assumed to fall off exponentially with height this is not as serious as might at first appear but would have to be taken into account in a more thorough investigation.

The negative result obtained from the attempt to estimate the upper atmospheric temperature from measurements of the profiles of the nitrogen bands has interesting consequences. Vegard[15] has for many years used the 3914 Å and 4278 Å bands appearing on his auroral plates to give an estimate of the temperatures of the auroral regions. The values he has obtained have been nearly constant at approximately -50°C for aurora occurring at widely differing altitudes, including in some cases sunlit aurora. These results have not agreed well with those obtained by other means - by rockets for example. It is thought that the reason for this may be that, because of the low density of the upper atmosphere, the conditions required for the effective temperature to be the gas temperature, are not fulfilled.

This method of measuring temperature, however, can still be used to estimate atmospheric temperatures provided the required conditions are fulfilled. This is much more likely to/

to be the case if a forbidden transition is used. With this the de-excitation probability is much less than for an allowed transition and so the time between excitation and de-excitation is much longer so allowing the molecule to settle back into thermal equilibrium with its surrounding before de-excitation. Such forbidden bands do occur in the night airglow spectrum and have been used by Meinel[16] and others to give valid temperatures for the upper atmosphere.

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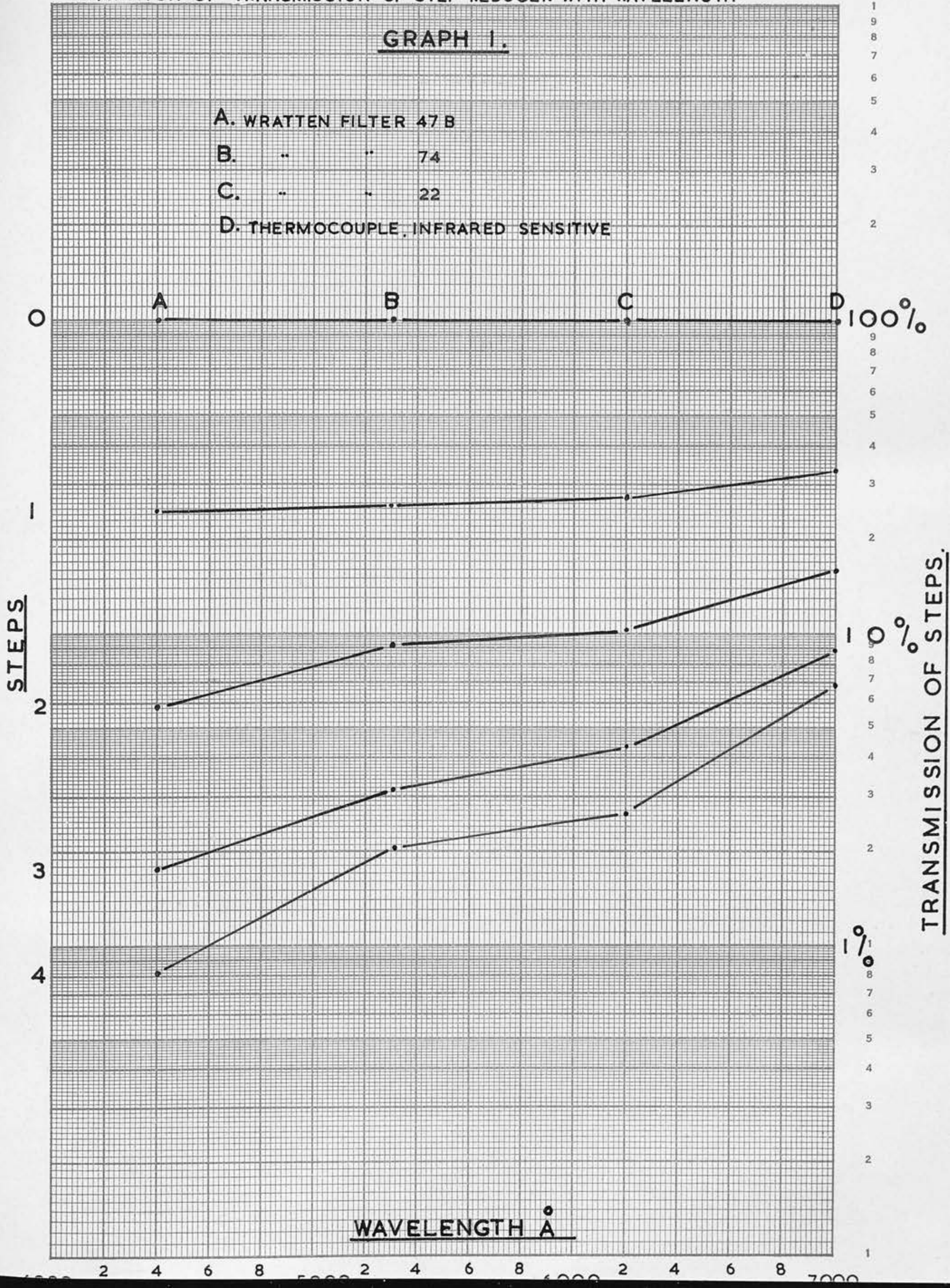
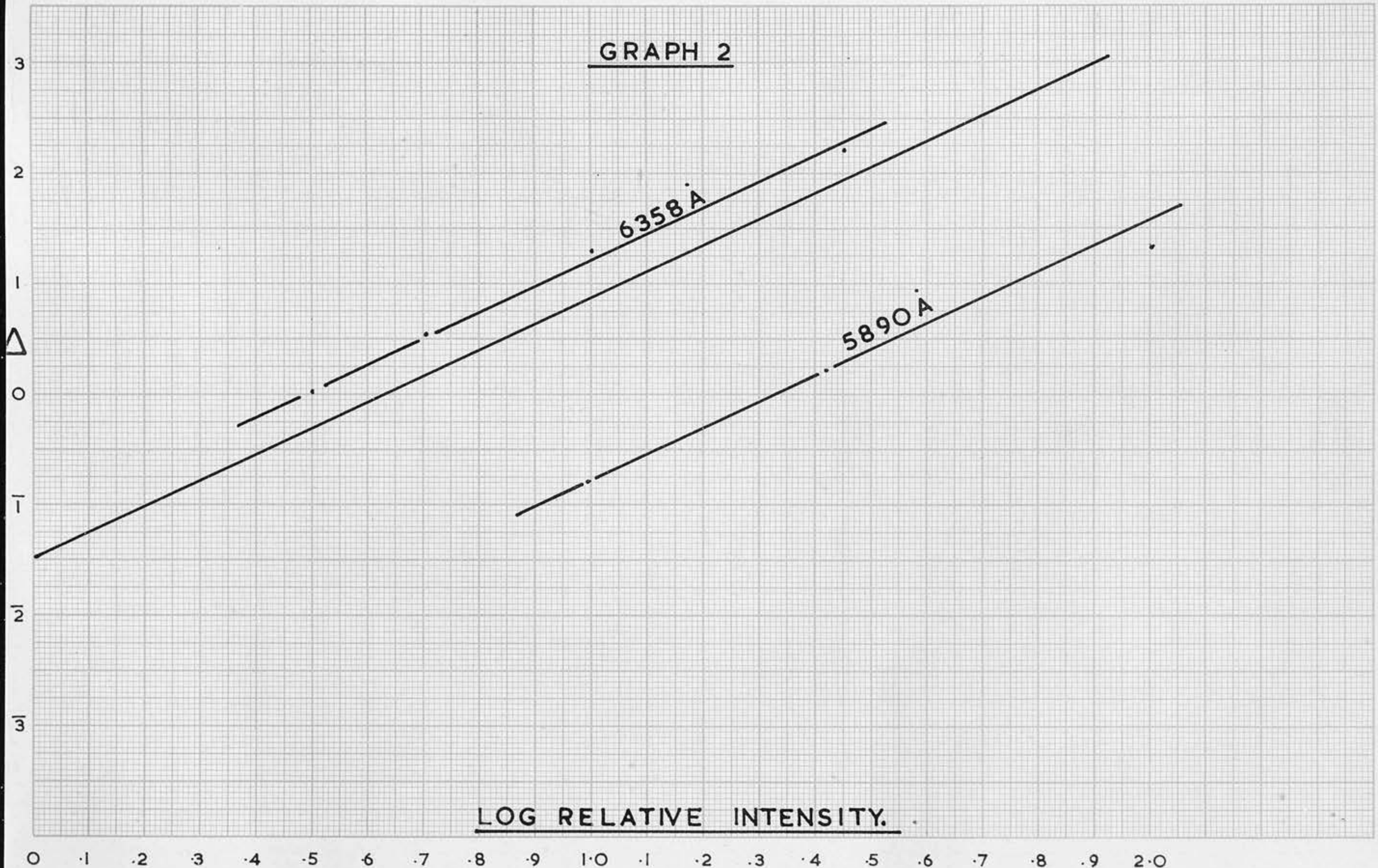
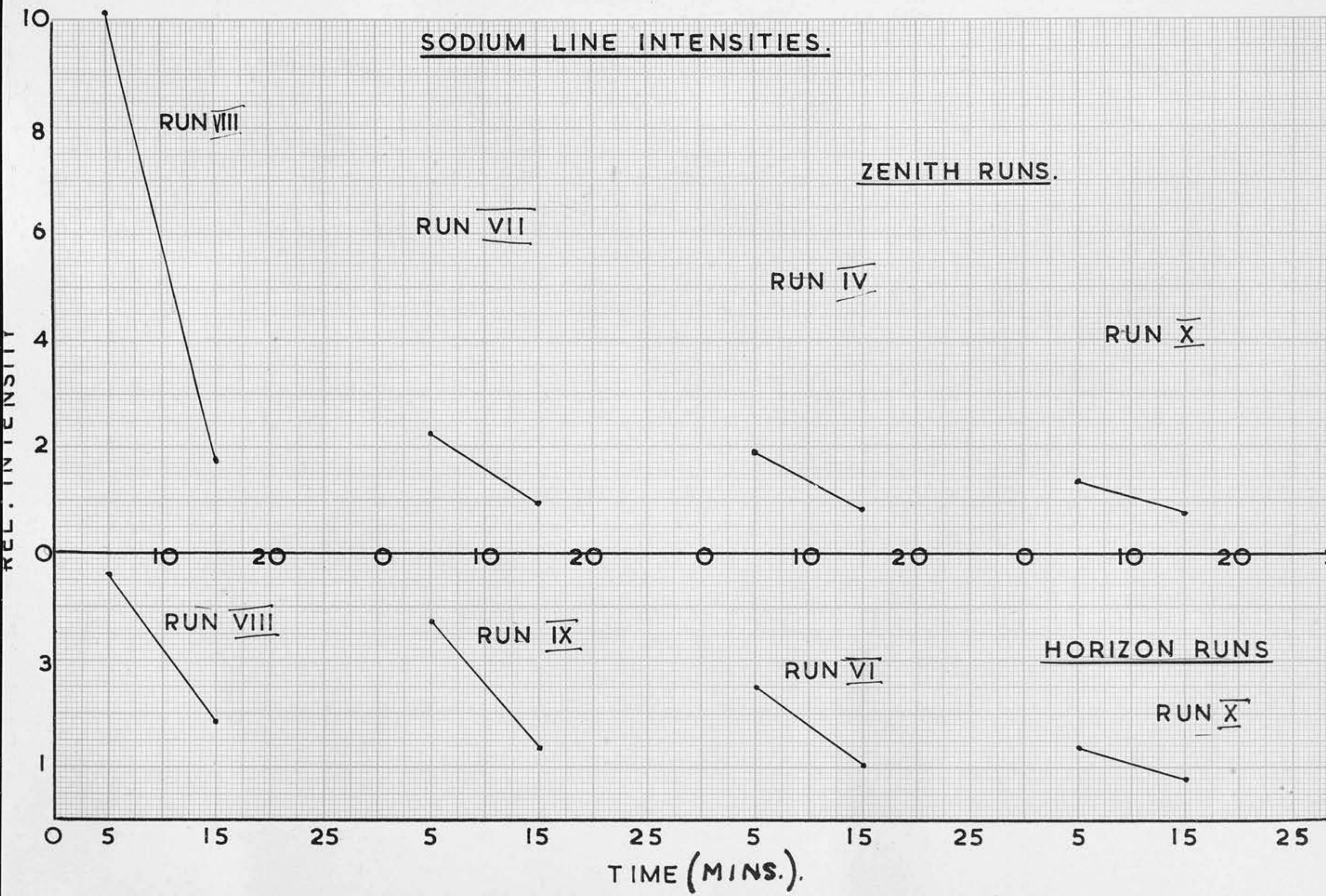
VARIATION OF TRANSMISSION OF STEP REDUCER WITH WAVELENGTH



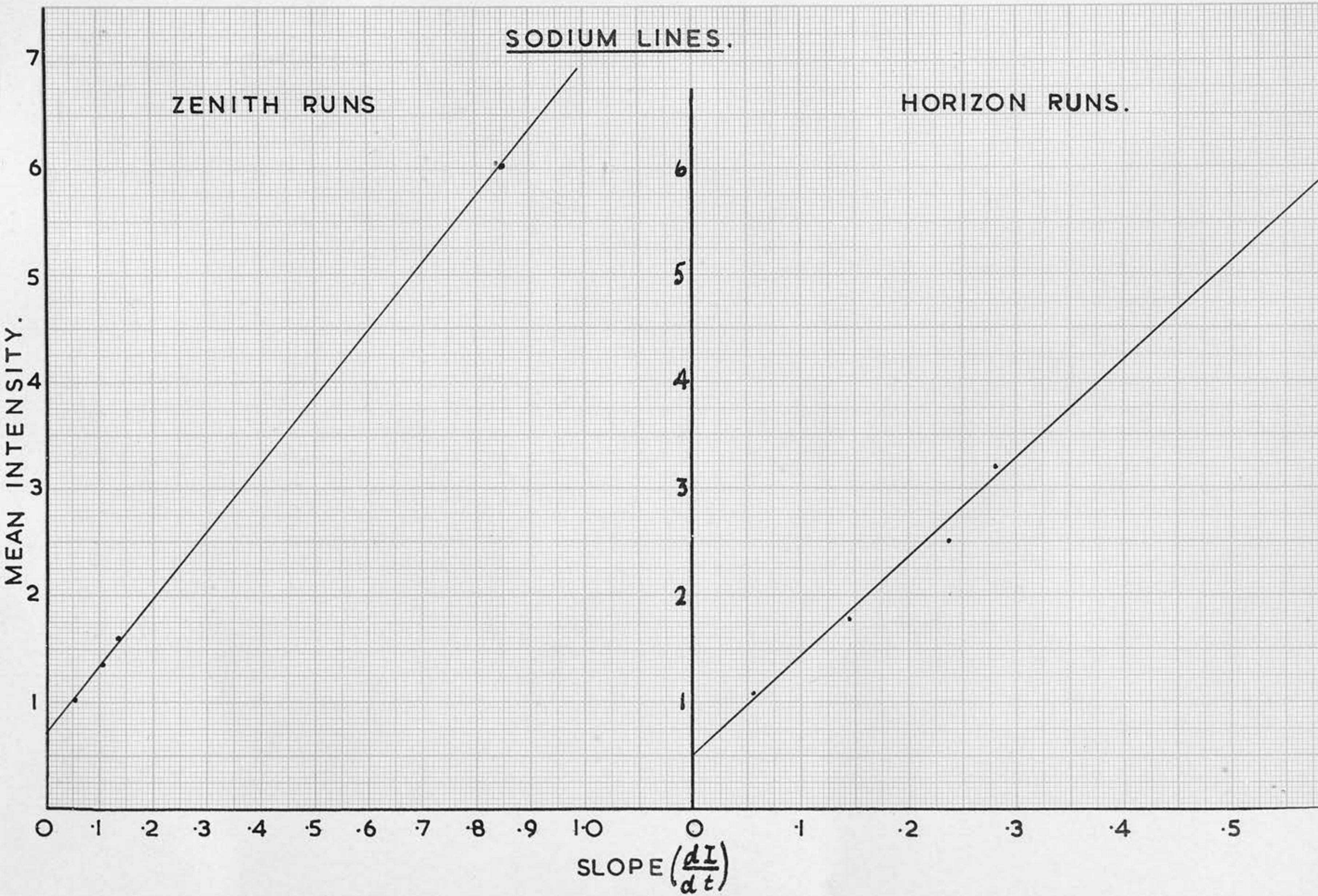
PLOT OF Δ AGAINST LOG RELATIVE ITENSITY FOR RUN IX.



GRAPH III & IV

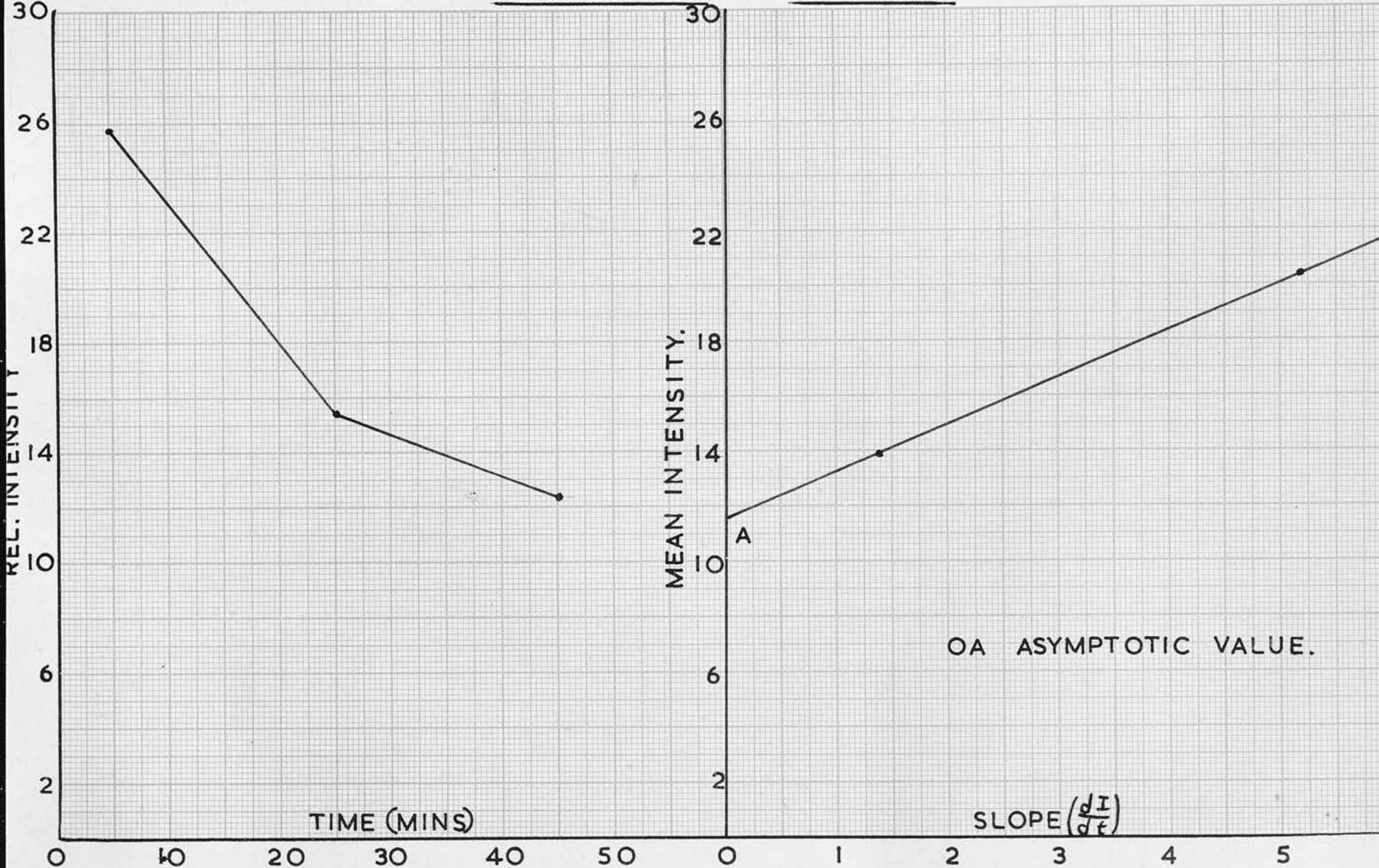

SODIUM LINE INTENSITIES.
REL. INTENSITY
10
8
6
4
2
0
3
1
RUN VIII
RUN VII
RUN IV
RUN X
ZENITH RUNS.
RUN VIII
RUN IX
RUN VI
HORIZON RUNS
RUN X
10 20 0 10 20 0 10 20 0 10 20
0 5 15 25 5 15 25 5 15 25 5 15 25
TIME (MINS.)

GRAPH V.


SODIUM LINES.
ZENITH RUNS
HORIZON RUNS.
MEAN INTENSITY.
1
2
3
4
5
6
7
0 ·1 ·2 ·3 ·4 ·5 ·6 ·7 ·8 ·9 1·0
0 ·1 ·2 ·3 ·4 ·5
SLOPE $\left(\frac{dI}{dt}\right)$

GRAPH VI

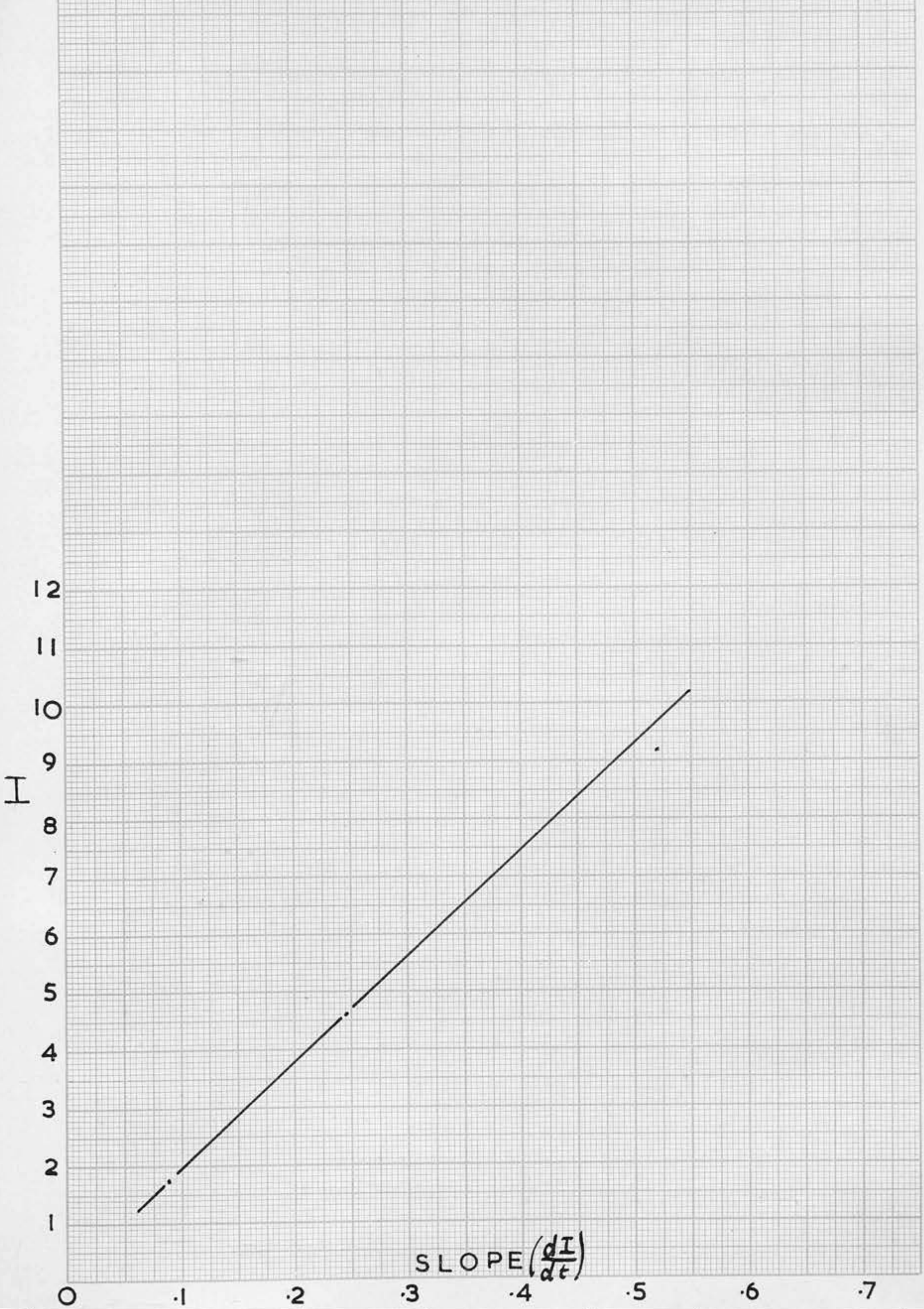
HORIZON RUN IX – RED LINES.



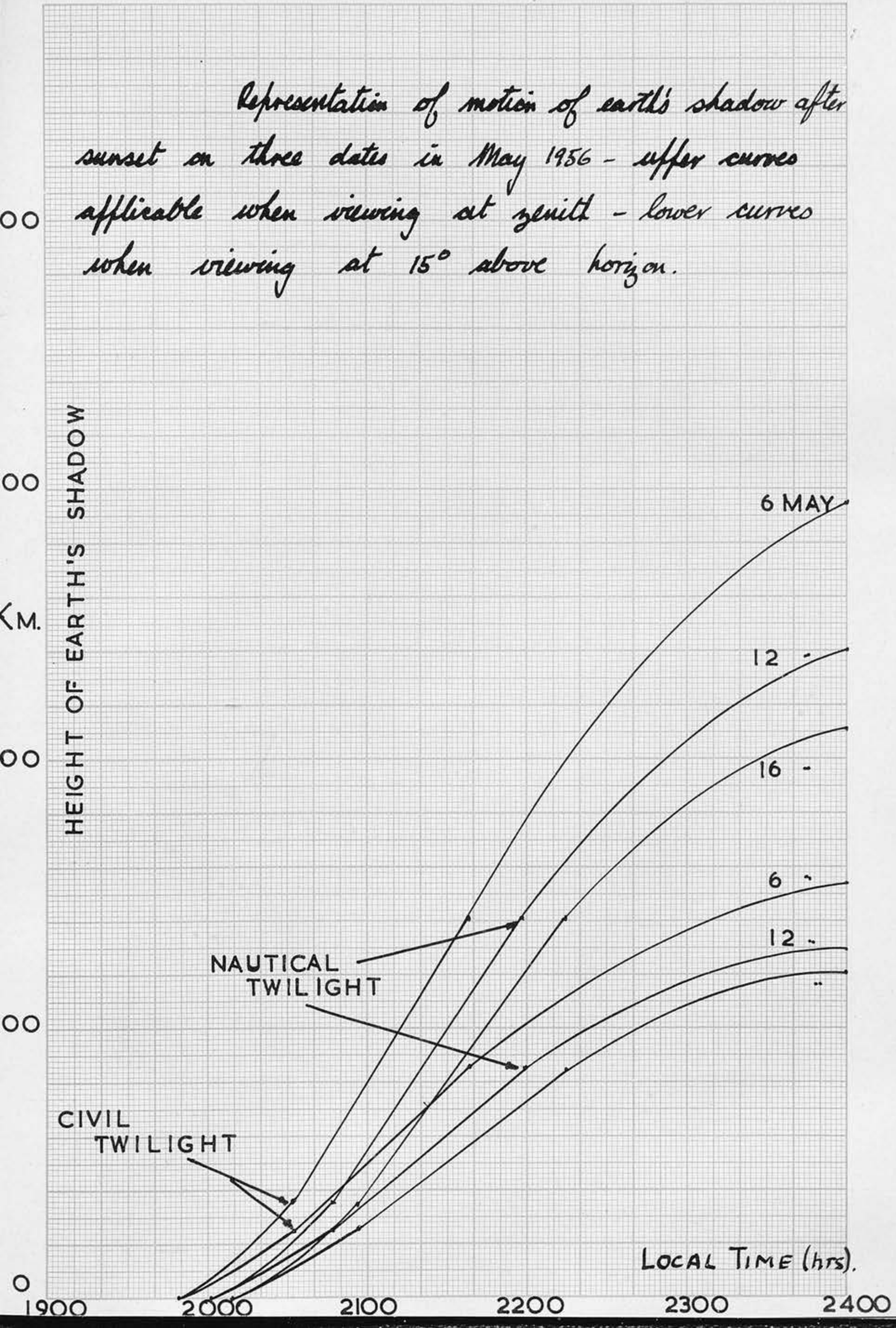
RED LINES—COMBINED CURVE.

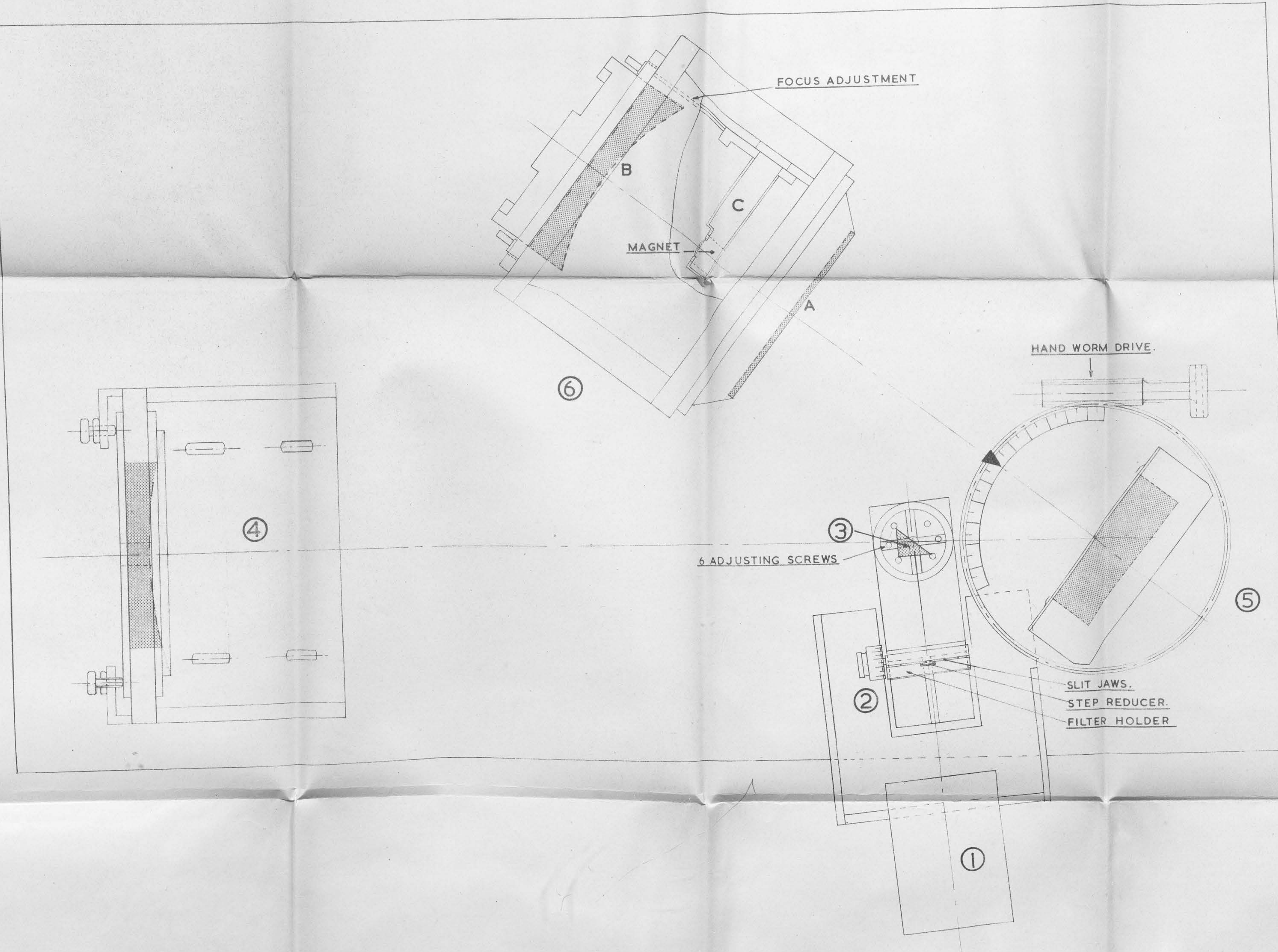
HORIZON RUNS

GRAPH 7.



GRAPH VIII


Representation of motion of earth's shadow after sunset on three dates in May 1956 - upper curves applicable when viewing at zenith - lower curves when viewing at 15° above horizon.
HEIGHT OF EARTH'S SHADOW
KM.
00
00
00
00
0
6 MAY
12 -
16 -
6 -
12 -
-
NAUTICAL TWILIGHT
CIVIL TWILIGHT
LOCAL TIME (hrs).
1900
2000
2100
2200
2300
2400



FOCUS ADJUSTMENT
B
C
MAGNET
A
⑥
HAND WORM DRIVE.
④
③
6 ADJUSTING SCREWS
⑤
SLIT JAWS.
STEP REDUCER.
FILTER HOLDER
②
①

SCALE~HALF FULL SIZE.

SCHEMATIC LAYOUT OF AURORAL SPECTROGRAPH.

UNIVERSITY OBSERVATORY.

ST. ANDREWS. 1·7·56 (F.D.A)